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THE FUTURE OF THE BIOSCIENCE PROGRAM

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HEARINGS

BEFORE THE

SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS

OF THE

COMMITTEE ON SCIENCE AND ASTRONAUTICS U.S. HOUSE OF REPRESENTATIVES

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THE FUTURE OF THE BIOSCIENCE PROGRAM

WEDNESDAY, NOVEMBER 12, 1969

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on Space Science and Applications,
Washington, D.C.

The subcommittee met at 10 a.m., in room 2325, Rayburn House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. Karth. The subcommittee will be in order.

Dr. Naugle and your associates from NASA are certainly welcome to the subcommittee again.

The distinguished chairman of the Committee on Science and Astronautics has instructed this subcommittee to look into the status and the future of our space biological program. The chairman has a meeting this morning before the rules committee on what is commonly referred to as the Miller bill, which I know you people are also interested in, as well as the academic community in general. But before the chairman goes, I would like to ask that he say a word about the hearings that we are about to embark upon.

Mr. Chairman.

Chairman Miller. Mr. Chairman, I am very much concerned with the subject of these hearings. I am sure you all are, too.

When doubt finds its way into the minds of people, because of the failure or cancellation of a biosatellite mission, in order to clear up those doubts and to satisfy ourselves we should have these hearings to determine whether or not men can be sustained in space for long periods of time.

I was interested in reading the other day a magazine piece in which one of the Russian astronauts was quoted as questioning whether men could stay in space for a long time. I think there would be no justification for the expenditures of vast sums of money to find out that, in the end, we had overlooked the fact of proving this to our own satisfaction.

So, to protect NASA, to protect this committee, and to protect the Congress, I have asked Mr. Karth to undertake these hearings. I know he is going to undertake them with his usual thoroughness. The hearings cast no reflection on anyone. It is just to make doubly sure that I have asked him to go into the subject.

I am glad you are here and I am only sorry I cannot remain. If I can make the next meeting I shall be here.

Mr. Karth. Thank you very much, Mr. Chairman.

Gentlemen, as the chairman has indicated, the subcommittee has been called together for the purpose of exploring the future of our

bioscience program in space. The necessity for this is that, as of this date, we have no program.

The original fiscal year 1970 budget, the members will recall, contemplated two biosatellite missions in which a primate was to stay in earth orbit for approximately 30 days, in order to investigate the effects of weightlessness on the nervous system, on the heart, and on alertness and physical coordination. Then in April, in the revised NASA budget submitted to Congress, we were notified that, and I quote:

> The second launch of an automated spacecraft mission with a primate experiment; namely, Biosatellite F, is being canceled. This will mean that the launching of Biosatellite D (later numbered Biosatellite III) scheduled for the second quarter of 1969, is the last of a series of automated biological experimental spacecraft.

In other words, we were putting all our eggs in one basket, in the expectation that Biosatellite III would be wholly successful. This subcommittee questioned NASA's judgment on this point. And, as a result of being somewhat dissatisfied with the expectations that some saw in Biosatellite III, we restored to the budget the $12 million item originally requested for the second primate flight. The House sustained the committee's position in passing the NASA authorization bill. The Senate, however, returned to the dollar figures of the administration budget and thereby eliminated the second biosatellite flight.

My concern with this problem is not new. I raised the issue of the adequacy of our biosatellite program as early as the summer of 1966, and I have raised it numerous times since then.

So that is where we stand today. The NASA bill has been passed by the Congress essentially as requested by the administration in April.

However, the first biosatellite flight, planned as a 30-day mission in June and July, was not entirely successful. As we all know, the monkey, Bonnie, became seriously ill in space and died 12 hours after he was brought down to earth on the ninth day.

Now, the question is, Where do we go from here? Nothing more is scheduled in the way of flight tests of the biological effects of weightlessness in space, except the remaining Apollo and post-Apollo manned space flights.

Is it our intention to use man as our test animal in the planned long-duration voyages to the moon and the planets, and in the proposed manned space station? Or should we try first to learn more about the hazards to anatomy of such flights by further exploration with monkeys or other animals? Or are we so sure there are no adverse health effects on man that we don't have to do anything in terms of animals?

The longest period of time that man yet has been in space is 14 days, in the Gemini 7 flight in December of 1965. It is my understanding that the proposed space station program, in the not too distant future, will require individuals to remain up in space 56 days; and, of course, later, in the proposed manned flights to the planets, men would have to be in space for a year and half or longer.

So that is why we have called these hearings. In the next 2 weeks we expect to hear from the best experts we have been able to summon from the Government, from the scientific community, and from the medical profession. Today's hearing is given over to the National Aero-

nautics and Space Administration and the leaders of that agency whom we feel are best qualified to initiate the hearings, particularly from the Agency's standpoint.

So it is my pleasure at this time to call upon Dr. John E. Naugle, Associate Administrator for Space Science and Applications, who will introduce the other NASA witnesses as he deems necessary.

Dr. Naugle.

STATEMENT OF DR. JOHN E. NAUGLE, ASSOCIATE ADMINISTRATOR FOR SPACE SCIENCE AND APPLICATIONS, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. NAUGLE. Mr. Chairman and members of the subcommittee, we welcome this opportunity to review the results of Biosatellite III, to discuss their relevance to future manned space flights, and to assess their implications for planning the future bioscience program. We are now analyzing the results of that mission, the recommendations of the bioscience community, and the needs for additional biomedical data for long-duration manned flight to determine the most appropriate bioscience program for this country for the decade ahead.

I plan to present a short statement recalling the background and present status of the bioscience program. Dr. Reynolds will discuss the results of Biosatellite III and their implications. I also have with me Mr. Charles Wilson, who is the project manager for the biosatellite project, and Mr. Jack Dyer, who was the operations manager for Biosatellite III.

The NASA bioscience program began in the summer of 1962 when a group of prominent biologists met at the University of Iowa under the auspices of the National Academy of Sciences. The group was asked to recommend methods by which the space program could help solve basic biological problems. They suggested that we attack the problems of the biological effects of weightlessness, the biological effects of the disassociation of living systems from earth's time-regulating influences, and the biological effects of radiation in space. These recommendations gave rise to the space biology portion of our program which, together with the exobiology program, became the NASA bioscience program. In order to accomplish the program recommended by this group we started the biosatellite program.

Based on these recommendations, we planned a three-part biosatellite program, with each part having two flights. The first part was to determine the combined effects of weightlessness and radiation on simple forms of life such as cells, bacteria, plants, and very small animals; this part involved Biosatellites I and II. As you will recall, Biosatellite I was lost because of a failure of the retrofire mechanism in the spacecraft. Biosatellite II, which was successfully flown in 1967, provided us with excellent information on the effects of weightlessness, alone and combined with radiation, on the basic processes of reproduction, growth, and development.

The second part was to determine the effects of weightlessness upon the central nervous, cardiovascular, and certain metabolic systems of a small subhuman primate. This was undertaken with the launch of Biosatellite III on June 28, 1969. We had intended to continue this flight for a period of 15 to 30 days, but, on the ninth day, physiologi-

cal deterioration of the monkey made it necessary for us to order the capsule to deorbit. The capsule, with its live passenger, was safely recovered off the island of Kauai and returned to Hickam Air Force Base where, 12 hours later, the monkey died.

Despite the early termination of the flight and the unfortunate death of the monkey, the flight provided a large amount of high-quality data. At this time, the experimenters have completed the preliminary analysis of those data. That preliminary analysis and their interpretations were presented to the public and to the rest of the scientific community on October 22, 1969. As you are undoubtedly aware, their conclusions have been received with great interest by other scientists and some differences of opinion have already arisen.

It will take several months before the experimenters on Biosatellite III will have completed their analysis of these data, assessed their complete meaning and submitted their conclusions to their scientific colleagues for examination and validation. It is not until this process has been completed—until the data and conclusions have been reviewed and debated by the scientific community—until alternative conclusions have been brought forward and either accepted or rejected—that we can be sure of the significance of the results of Biosatellite III. Later, Dr. Reynolds will be discussing these preliminary results and their implications as we now see them. Then, of course, tomorrow as a part of the hearings, the experimenters on Biosatellite III will discuss the results themselves.

The third part of our bioscience program was to determine the effects of weightlessness upon the development, structure and function of plants, upon the growth of human cells, and upon the body rhythms and the composition and functions of organs and systems in small mammals. You will recall that, because of severe funding problems, this effort was deferred several times. In preparing the fiscal year 1970 budget, we found that we could not schedule a further deferment in an efficient manner. We, therefore, terminated, the effort on December 13, 1968.

Not very many people are aware of the fact that the biosatellites were among the most complex spacecraft developed by NASA. For example, the biosatellite is the only American satellite having a two-gas atmosphere of oxygen and nitrogen in orbit very similar to what we have here on earth. The temperatures were held within 5° F. of a prescribed optimum level. Humidity was controlled to within 45 plus or minus 5 percent, which is much more closely controlled than the average office building. And the spacecraft was stabilized so precisely that the accelerative forces were below one hundred-thousandth of that due to earth gravity.

Experimental procedures were performed by various automatic devices. Food and water was provided to the monkey automatically. He was subject to behavioral tests. Urine was analyzed automatically, and indeed the list of automated functions in the biosatellite experiments is very long.

As I mentiond, last December we eliminated the third part of the biosatellite program, first because of budgetary considerations, and also because we wanted to take a good hard look at where the total bioscience program should be going before spending more of our resources on flight programs. For the same reasons, we did not allocate

any fiscal year 1970 funds for the second flight of the primate mission, Biosatellite F.

On December 18, 1968, I asked the Space Science Board of the National Academy of Sciences to assist us in our review by conducting a study to consider all facets of space bioscience and, in addition, to give some attention to the value and relationship of space bioscience to the general field of biology. That study was conducted in Santa Cruz, Calif., last July. The report is under preparation and review by the Space Science Board of the National Academy of Sciences.

Also, on a broader basis, NASA has undertaken a review of the entire life sciences work within NASA, including space biology, aerospace medicine, biotechnology, bioengineering, human factors, and man-machine relationships. On August 12, 1969, Dr. Newell, the Associate Administrator of NASA, asked the National Academy of Sciences to assist us, NASA, in our review of the life science program, to take stock of what we have learned from past successes and mistakes, to determine what should be our goals and objectives for the future, and to decide the best and most effective way of achieving those goals and objectives.

The Biosatellite III findings are providing a better understanding of the biological changes observed in the manned space flight program. Simply stated, Biosatellite III validated in space information obtained from ground analogs of weightlessness and seen in manned flight. The results indicate that certain disturbances of man's physiology which have been observed in manned flight are due to the mechanisms which had been postulated in advance.

The preliminary examination of the results of Biosatellite III, together with the experience and information obtained by over 5,000 man-hours of space flight involving 20 different subjects, some of them with several flights, and flight durations of from a few minutes to 14 days, have led us to the conclusion that we can safely proceed with the 28-day dry workshop mission scheduled for 1972 and can prepare for progressively longer missions.

Biosatellite III provides evidence to support our plans and our ability to carry out the required studies on man related to fluid balance, metabolism, exercise, and cardiovascular deconditioning. These studies are included in the Apollo Application program. The experimental protocols will give us important data related to these phenomena, their variation with time, and further experience with methods for controlling adverse effects. There are provisions for monitoring this information and for transmitting it in near realtime to the ground.

The space station design concepts include biological and biomedical laboratory modules for the study of the effects of space flight on living organisms in both zero and in various levels of gravity. The space station, with the flexibility of the planned logistics systems, will make it possible to carry out the necessary experiments at various flight durations before committing man to very long flights, such as a Mars mission.

We are confident that our plans for both ground-based and flight experiments will insure the best possible protection of a man from any serious deleterious effect from space flight.

In summary, the Biosatellite III marked the end of the first era in space bioscience. We are now in the process of developing a new program, based on the results from both the Biosatellite II and III, using the competence of our centers and the appropriate subcommittees of the Space Science and Applications Steering Committee and the NASA planning and steering group. These plans will be strongly influenced by the reports from the Santa Cruz study and the NASA life sciences study.

We are planning to proceed with the 28-day dry workshop mission in 1972, to be followed by missions of steadily increasing durations carrying appropriate studies with man and animals to extend our knowledge of space biology and to qualify man for long-duration missions in space.

Mr. Chairman, that concludes my statement, and Dr. Reynolds is now ready to go into detail on the results of Biosatellite III.

Mr. KARTH. Thank you very much, Dr. Naugle.

Dr. Reynolds, will you proceed, please.

STATEMENT OF DR. ORR E. REYNOLDS, DIRECTOR, BIOSCIENCE PROGRAMS, OSSA, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Dr. REYNOLDS. Mr. Chairman and members of the subcommittee, the Biosatellite III mission constituted one of the most demanding missions of NASA's experience and also perhaps the most complex experimental array in the history of biological science.

The very complexity of the scientific investigation, as well as the engineering systems developed to implement it, have a strong bearing on our problem today. It makes the results very hard to comprehend at this early date when the data have not been fully analyzed. This complexity also causes a certain inherent confusion between the effects of the experimental methods and the effects of the principal variable being measured—the weightless state.

If you will bear with me in a rather technical explanation, I will try to convey my view of our present position as a result of the Biosatellite III mission by addressing the following points:

First—What were the objectives of the experiments themselves conducted in this mission and what have we learned from them?

Second—What additional observations were made which—while they were not specifically designed as experiments—shed light on the effects of weightlessness?

Third—What scientific implications arise from the observations and what hypotheses or questions are raised by them?

Fourth—What is the relationship between this mission and the implications for future manned flight missions?

Fifth—From the standpoint of a biologist, what should the future course of biological experimentation in space be as a result of the total accumulation of information now available?

As to the experimental objectives and results, the study of the effects of weightlessness and separation from terrestrial 24-hour geophysical cycles on central nervous system function was a principal objective of the mission. Dr. W. Ross Adey, principal investigator for the mis-

sion as a whole and for this study in particular, is to appear before this subcommittee tomorrow and will, I am sure, address himself to these experiments in detail. The principal results of the nervous system experiments presented by Dr. Adey so far are the appearance of disturbance of the relationship between the eyes and the organs of balance when eye movement was stimulated by the behavioral tasks during weightlessness, and a disruption of normal cyclic pattern of sleep. The EEG records, however, did confirm for the first time that all of the normal types of sleep do occur in weightlessness.

In the area of cardiovascular function, both arterial and venous blood pressure records were obtained throughout the flight and recovery. It is important to note here that this is an area of physiology in which the effect of weightlessness has been the subject of great interest in terms of space medicine.

In 1966, the Space Science Board of the National Academy of Sciences, undertook a study of the physiological problems of manned space flight. A report from this study on circulation was published recently and reflects the most up-to-date theories of cardiovascular responses to weightlessness. These theories state that the most important physiological effect of zero gravity is the reduction in weight of the long "columns" of blood in the body. This weight reduction results in reduced pooling of blood in the extremities, with greater amounts concentrated in the chest regions. Changes in the ratio of blood to air in the lungs, and increased blood volume due to increased fluid absorption from body tissues, are associated with this condition. The report predicts a resultant increase in the blood pressure in the large veins and the auricles of the heart which, through reflex mechanisms, causes the body to discard water in an attempt to eliminate the excess blood volume.

The reflex mechanism referred to above, called the Henry-Gauer reflex after its discoverers, had been predicted to occur during space flight. The phenomena of weight loss and certain blood changes observed in the astronauts were consistent with the activation of this reflex—however, the principal indicator of the operation of the reflex mechanisms; namely, the blood pressure in the veins near the heart, could not be observed in man because of the hazards associated with its measurement. The only existing way by which this measurement could be performed is by the implantation of catheters (that is flexible tubing) in the heart and in the blood vessels near the heart. This experiment was performed on the monkey in the Biosatellite III, under the direction of Dr. J. P. Meehan of the University of Southern California, with two catheters so located, and the data from this experiment showed clearly that the predicted increase in blood pressure in this location did occur very soon after the initiation of weightlessness. Prior to this experiment, it was not known whether the increase in blood pressure in the veins would be transitory or of long duration. The experiment showed that the increased pressure was long lived and that the normal state does not return quickly. Therefore, this reflex in combination with other factors about which we can only speculate, leads to a continuing drain on fluid reserves of the body. Later I will discuss why I think this reflex leads to a continuing drain on these fluid reserves. The ultimate deterioration of the monkey, probably from this mechanism, prevents us from knowing just how long

this condition may persist. This constitutes an extremely important experimental result of Biosatellite III in that it provides a crucial confirmation of a theoretical anticipated effect of weightlessness.

A third area of study had the objective of determining the balance of calcium exchange by the body as a whole and whether muscular deterioration occurred. This was to be done by determination of certain urinary constituents, calcium, creatine, and creatinine, under the direction of Dr. Nello Pace of the University of California at Berkeley, and Dr. Joon Rho, of the Jet Propulsion Laboratory.

Unfortunately, although the apparatus developed for this purpose operated correctly, the urine delivered by the animal was so dilute that the amounts of these materials present fell outside the normal operating range of the instrument. Therefore, the analysis of the data has proven very difficult so that the results are not available at present. Laboratory analyses for these and other constituents conducted postflight, however, give an indication of considerable loss of muscle and perhaps other body tissues during flight.

A fourth, closely related study, conducted by Dr. Pauline Beery Mack, of Texas Women's University, on loss of bone mineral, has shown a pronounced loss of bone mineral during the flight period.

As for additional nonexperimental observations, the abrupt and unexpected collapse of the flight monkey's physical condition has led us to an intensive study of other information available from the spacecraft engineering data in an effort to understand the causes of the animal failure.

The perfect operation of all components of the system produced such high-quality data, that it has proven possible, largely through the efforts of the spacecraft contractor's program scientist, Dr. J. Schull, to derive metabolic rates of the animal using both oxygen consumption and carbon dioxide production and to follow the rate of water loss by evaporation mechanism from the animal during flight, although these systems were not designed to get physiological data. Since these measurements were not experimental objectives, no provision was made to detemine these factors in the backup animal or in the other flight candidate animals.

The data, when considered in relation to the amount of urine excreated and the amount of water consumed by the monkey, yielded an interesting new finding. The loss of weight of the monkey (about 20 percent) was partially a result of an elevated loss of water through the skin in the early days of the flight. Since the flight, we are in receipt of a translation of a Russian publication entitled: "Problems in Space Biology" (NASA TTF–528), which, in a discussion of data obtained from cosmonauts on the Voshkod I flight, points to a problem of high water loss through evaporation. It states:

> It is interesting to note that despite the fact that the cosmonauts were completely satisfied in their subjective requirements for food and water, their weight during the flight decreased: . . . Specially conducted calculations for perspiration, in particular, and other data from calculating the water balance in the organism, indicate that the decrease in weight occurred mainly because of moisture loss by evaporation. despite the optimum conditions of the microclimate.

Associated with this early period of high evaporative water loss was an elevation of metabolic rate and a gradual loss of body tem-

perature, which occurred in spite of the normal atmospheric temperature of the capsule.

Analysis of data on total water intake and output during the Biosatellite III flight indicate that the subject experienced a rapid net loss of water early in the flight, which, though it slowed somewhat later in the flight, continued as a level that eventually prevented the animal from maintaining an adequate blood pressure. When this situation developed, the collapse of the animal intervened rapidly, first with loss of alertness and cessation of drinking, and then with cardiovascular failure.

As in all scientific research, an experiment often raises as many questions and answers. A crucial question raised by this flight is why the effects cited above were more severe in the monkey than in man, and whether the differences are sufficient to assure that man's condition will not degrade with increasing flight duration.

There are three important differences between the monkey flight and the current concept of manned flights. The first is restraint. Restrained animals in ground-control conditions undergo physiological changes similar to those observed in the flight animal. For example, the dogs maintained as ground-control animals for the Cosmos 110 flight by the Soviets lost in restraint about 16 percent of the weight lost by the animals in ground-control conditions undergo physiological changes due to restraint are not nearly as drastic as those seen in the flight animal, but final validation of these findings must await confirmatory flight experiments.

Mr. KARTH. Dr. Reynolds, may I interrupt to ask one question to get something straight in my mind.

This is true, I assume, when animals are not accustomed to being restrained, more so than after long periods of training which these animals have gone through in a condition of being restrained. Am I correct in that assumption?

Dr. REYNOLDS. The restraint brings about a weight loss even after having become accustomed to restraint.

Mr. KARTH. Is it as acute?

Dr. REYNOLDS. Not as much as what we observed in flight.

Mr. KARTH. What is the difference? Bonnie, for example, was trained to a climate of restraint. What is the difference in the degree of this phenomenon, if that is what it is, between an animal that has not been trained with restraint and Bonnie, for example?

Dr. REYNOLDS. This is the reason I specifically used the example of the Soviet dogs rather than our flight animals. Since this was not a subject of experiment, we did not in fact get accurate measurements on this in the backup animals for Biosatellite III. We do have data from previous ground test experiments which we are now developing the data for which we hope will give us this comparative number.

In the case of the dogs, where the animals were maintained both in flight and prior to flight in a condition in which their weight was stabilized by feeding them by a tube in the stomach—they were fed enough water and food to maintain body weight—the change observed between the flight animals and the ground animals was 29 percent loss of weight by the flight animals and about 5 percent loss of weight by the ground animals with equal amounts of restraint in both cases.

Mr. KARTH. So about 25 percent greater loss in flight as opposed to ground restraint.

Mr. PETTIS. What period of time?

Dr. REYNOLDS. The flight period was 22 days. They were restrained and followed for a period before flight. I don't know the exact period. A week or more.

Mr. KARTH. What you are saying is that loss in flight was 500 percent greater than on the ground.

Dr. REYNOLDS. Yes.

Mr. KARTH. Thank you.

Dr. REYNOLDS. A second factor which may have contributed to the deterioration of the flight animal was the amount and kind of surgery which were necessary. Although the best techniques available were used for these experiments, we need improved technology for obtaining these data. In addition, it would be preferable to attempt fewer measurements, with correspondingly less surgery, on a given subject, if sufficient flight rates permitted.

The third factor making the monkey more susceptible to deterioration is the markedly different surface-to-volume ratio between a monkey and an astronaut. This difference in ratio would cause the monkey, though he lost water through the skin surface at the same rate as would a man, to suffer much more serious effects because of the proportionally small fluid reserves.

These factors are the most important differences between this animal flight and manned flight, in my view. You may recall that immediately after the Biosatellite III mission, there was speculation on two other possible causes of the difficulties we encountered. Contrary to these early reports, the temperature experienced by the test animal was normal throughout the flight, and was not a factor in the deterioration that was experienced. In addition, it had been determined, through extensive testing prior to the mission, that isolation does not have adverse effects on this species.

As to the implications of these results for manned space flight: I would say that these results define certain questions that should provide clear guidelines for future experiments in animals, and to the extent possible on man, both in ground-based research and in flight.

As to the shape the future program should take: I believe we have a number of clearly defined areas of considerable scientific and practical interest that we did not have when the biosatellite program was initiated. These areas derived largely from the successfully conducted experiment on Biosatellites II and III, but they are confirmed by analogous observations from other programs, both by the medical observation in manned space flight and by the Soviet space program.

I feel that the bioscience program is at a crossroad where we can narrow the scope of questions to be asked and focus on circumscribed issues in which biological investigations in space are of paramount importance. These questions include four major areas of concern, the first three of which relate to possible biologic effects of weightlessness, and the fourth to circadian and other biological clocks:

1. What are the effects of prolonged exposure to low gravity on vital functions of higher organisms, with special emphasis on the results of Biosatellite III, which suggest major effects on blood pres-

sure, water and calcium balance and their possible neuorendocrine mechanisms?

Mr. KARTH. How are we going to get the answer to that question, Doctor?

Dr. REYNOLDS. I feel we are going to need additional both ground-based work and flight experiments involving animals.

Mr. KARTH. Are there any such projects now in the NASA program?

Dr. REYNOLDS. There are no approved projects at the present time.

Mr. KARTH. You feel it is essential we do have this kind of a program in the future?

Dr. REYNOLDS. Yes, sir; I do. We are at present studying the methods by which we can carry out such studies in the space workshop program and the space station.

Mr. KARTH. Thank you. With animals?

Dr. REYNOLDS. Yes, sir.

Mr. KARTH. And with man simultaneously?

Dr. REYNOLDS. Yes.

Mr. KARTH. Is it your judgment that it is good to carry these experiments out simultaneously?

Dr. REYNOLDS. Yes, sir; it is.

Mr. KARTH. If we really don't know the effects of prolonged space flight and if they may be dangerous or hazardous, it just seems to me, as a practical individual, that maybe we ought to conduct those experiments rather exhaustively on animals before we do it simultaneously with animals and man. You would disagree with that approach?

Dr. REYNOLDS. I believe that we can expect the durations that are contemplated for the early part of the workshop to be adequately handled by continuous monitoring of the physiological condition of the astronauts. The longer term flight later on in the program will be supported by the results obtained during the early flights and from the results that we hopefully will have on animals for long durations.

Mr. KARTH. You are talking about the initial 28-day flight as opposed to the 56-day flight?

Dr. REYNOLDS. Yes, sir.

Mr. KARTH. If our experience at the end of the 28-day flight is not a good experience, then we would probably be in a position to cancel out flights of additional time—for example, the 56-day flight. Is that really what you are saying?

Dr. REYNOLDS. It would be possible to have additional flights, the length of which could be adjusted on the basis of the observations made in the 28-day mission.

Mr. KARTH. Then will there be a constant monitoring, Doctor, of man during the 28-day flight?

Dr. REYNOLDS. Yes sir. I have been talking with General Humphreys about this specifically, and he, of course, is scheduled to testify here later. My understanding is that a number of the normal physiological parameters that have been used in the past will be monitored as well as the weight changes on a daily basis and also fluid balance change, urine output, water intake, food intake.

Mr. KARTH. These monitorings, of course, would take place using normal convention methods, no implantations, for example, like the primate had inbedded in it?

Dr. REYNOLDS. No, sir.

In the case of the primate we were not able to follow body weight change which in itself, I think, is a very significant measurement and this is a new technique that has been developed for manned flight. It should be a very good sort of overall method of assessing these changes that I am referring to.

Mr. KARTH. So what you are saying really is if during the 28-day flight it appeared that man was suffering to an excessive degree the effects of prolonged weightlessness, then you would end the flight.

Dr. REYNOLDS. You would return the astronauts. But that doesn't mean the workshop mission need be terminated because there are opportunities to send men back for another visit.

Mr. KARTH. My question was really on the 56-day flight, I think, as opposed to the 28-day flight which itself is twice as long as any we have experienced up to this point, the longest flight being 14 days.

Thank you.

Dr. REYNOLDS. I was discussing four major areas of concern.

The second is, What are the neurological and behavioral effects of low g on sensorimotor coordination, including balance and eye-hand functioning and more complex behavioral mechanisms in animals and man?

Third. What are the effects of gravity at the cellular level on plants and animals?

Fourth. Do normal periodicities (that is, circadian rhythms, daily rhythms, and other biologic clocks) observed in organisms on earth, persist or change under conditions of space flight and are new periodicities established? How do changes in rhythms, if they do occur, affect vital physiological functions, and behavior of the organisms during space flight?

These four questions are not exhaustive, but they indicate these salient issues that seem to hold the major interest for biologic investigation in space. None of them can be answered without a combination of in-flight and ground-based research.

I should like to digress a bit to give an interesting example of the way the ground-based S.R. & T. program is essential in deriving the utmost benefit from flight experiments.

Prior to the Biosatellite III flight, we recognized the fact that weightlessness has an effect on fluid balance due mainly to the abrupt weight loss experienced by the astronauts and cosmonauts. The reflex increase in urinary output brought on by increased blood pressure in the veins, through the Henry-Gauer reflex referred to above, was one of the hypotheses considered a very likely cause of this phenomenon. The existence of this reflex was demonstrated by Dr. Otto Gauer, now of the University of Berlin, and Dr. James Henry, of the University of Southern California, when they were both at Wright-Patterson Air Force Base, using inflatable balloons in the auricles of the hearts of experimental animals to simulate increased blood pressure in the veins.

Thus we expected an increased water output of the flight animal, but there was some basis for the thought that the previous cause of the water imbalance problem in both the Soviet cosmonauts and the U.S. astronauts was failure to drink enough water, implying a failure of the thirst-producing mechanism. In fact, in the selection of the flight monkey, we deliberately picked an animal that was a good

drinker, hoping this would help in his accommodation to the increased urinary loss.

When the events of the flight demonstrated to us the extremely serious degree of the water balance problem, we not only started our intensive study of the spacecraft environmental data, but also scoured our available background of S.R. & T. information to develop an explanation or hypothesis for the phenomenon.

At the University of California at Davis, Dr. Arthur H. Smith has been exposing animals to chronic accelerations on the centrifuge. He has found that one of the proteins in the blood, the albumin, serves as a mechanism to adjust for distribution of fluid between the blood and tissues when the hydrostatic pressure changes due to altered gravity. This mechanism may well explain why the elevation of venous pressure was not of brief duration but instead continued to extract fluid out of the tissues, because the albumin level in the blood had not had time to adjust to the weightless environment.

The high proportion of water loss by the skin was a complete surprise although subsequent to the flight we have encountered some hints that this had occurred in manned flight. In addition, we have recently learned that Dr. Robert Johnson, of the University of Illinois, also working with support of the S.R. & T. program, has just found that the antidiuretic hormone secreted by the pituitary gland and involved in the urinary increase brought on by the Henry-Gauer reflex, also has a similar regulating effect on the sweat glands of the skin in man.

Finally, a continuing puzzle to the biosatellite scientists has been the lack of shivering of the monkey when his body temperature began to fall. Normally, such a drop in temperature would have stimulated so-called thermogenic responses to maintain body temperature. The absence of these responses has been a complete enigma. It has just been called to our attention by Dr. Robert E. Smith, also of the University of California at Davis, that mammals, probably including the monkey and man, have a sensor in the spinal cord at the bottom of the neck which is richly supplied with blood from the chest. When it is kept warm, as it would be under the conditions of engorgment of the blood vessels of the chest, shivering is blocked by the inhibition of the brain mechanisms responsible for the thermogenic response. This may well explain the lack of shivering, at a reduced body temperature, seen in Biosatellite III.

Mr. KARTH. Doctor, what was that reduced body temperature?

Dr. REYNOLDS. Actually we don't know quite how far down it fell because it went beyond the range of the thermistor.

Mr. KARTH. What was that range?

Dr. REYNOLDS. The bottom was 34° C.

Mr. KARTH. What is normal?

Dr. REYNOLDS. About 36½. There is an oscillation of a couple of degrees, but this animal started around 38° or 38½°.

Mr. KARTH. The animal started at 38½ and went below 34?

Dr. REYNOLDS. Yes. But this was with normal atmospheric temperature in the capsule.

Mr. KARTH. I understand. That did not change.

Dr. REYNOLDS. No, sir.

I might say we had two thermistors in this animal, one in the brain and the other at another location in the body. These have different

normal temperatures; so the brain temperature was slightly above 38 at its height at the beginning of the flight and fell to below 35°. The other thermistor registered about 36° normally and fell to about 33° which was the bottom of the range of the thermistor. We know it fell below 33 in that case.

Mr. KARTH. Also one of your urine experiments did not give you the information you needed really because it, too, did not measure to the limits which apparently the monkey fell to; is that correct?

Dr. REYNOLDS. I think when Dr. Pace——

Mr. KARTH. Bear with me, not being a medical man. Do I understand that two of the experiments designed to measure certain physiological changes in the monkey worked properly, but were not designed to go to the limits to which the monkey went?

Dr. REYNOLDS. That is correct, sir.

Mr. KARTH. Are those the only two?

Dr. REYNOLDS. Certain measurements were to be made on the animal before and after flight by Dr. Nello Pace on the distribution of water between blood vessels and tissues, and it was not possible to complete the postflight part of those measurements because of the animal's death. Some of it was done. Some of it could not be done.

Mr. KARTH. What was the result of that which was done?

Dr. REYNOLDS. I had mentioned earlier that this did give evidence of loss of tissue during the flight, probably muscular tissue, perhaps other tissues. Dr. Pace will, of course, appear here tomorrow and perhaps he can go into more detail on this.

Mr. KARTH. Thank you, Doctor.

Dr. REYNOLDS. I would like to emphasize that all of the above possible explanations are speculative, as they apply to this animal, because they were not measured on this animal, but they do provide a theory consistent with the observations and specific experiments. Further experiments on the ground and in flight can now be performed to test such a total theory with a good likelihood of achieving a level of understanding that will help greatly in the support of astronauts in long-term flight.

I cite these examples to show the indispensible contributions of this on-going supporting research and technology to the flight program, Biosatellite III. Without this on-going research, we would almost be without clues to aid us in understanding the dramatic results of the flight, and further experiments would be less focused and much less likely to be productive of understanding.

In closing, I would like to advise this committee of some of the more significant technological developments which have accrued from the Biosatellite III and which are improving the status of man on earth.

The major developments would include the following:

1. Development of brain and muscle implanting techniques for long-term recording. These have been applied directly to neurosurgical problems in man with useful contributions to new knowledge about the human brain from these deep implants.

2. Development of methods for collection of urine directly from the bladder for periods as long as 60 days without occurrence of infection in the bladder or collection apparatus. This technique has been applied successfully by its developer, Dr. A. K. T. Cockett, in the manage-

ment of pediatric urinary problems in children born with abnormalities of the urinary tract.

3. Development of radio telemetry techniques for the acquisition of brain, heart, and muscle data in a freely moving subject. These radiotelemetry techniques have been applied in many neurological and psychiatric problems in human patients, including sleepwalking, epilepsy, and schizophrenia.

4. Development of techniques which allow computer analysis of brain and heart data in an "on-line" fashion. UCLA has developed techniques for transmission of these data by ordinary telephone lines directly to their computing laboratory from any part of the country. These techniques have been applied to problems of divers suffering from "bends" in a Navy recovery chamber located 30 miles from the laboratory. The technique offers many advantages in studies of patients in their home environments, including children playing in the vicinity of their homes.

5. Development of new and comprehensive computing analysis methods, which have been applied to performing man as well as to the flight animal. These methods involve "pattern recognition" techniques, in which the computer essentially makes a diagnosis of the status of the individual, particularly in terms of levels of attention and states of wakefulness and sleep. These methods have urgent application in problems of pilots, astronauts, and automobile drivers, where performance may be degraded by fatigue. The sensitivity of the techniques now extends into assessment of phychological stress under questioning, and in evaluation of correctness or incorrectness of decisions made by animals and man. These new methods will undoubtedly have greater application to many sociological problems and will be further developed in the future.

6. The development of automated urine analysis by the Jet Propulsion Laboratory. It is expected that devices similar in type will find a great deal of use in hospitals and medical laboratories and provide more complete and economical analyses and diagnoses for larger numbers of patients.

7. Finally, the bone densitometry methods developed by Dr. Mack have now been used in the diagnosis of disorders of the bone in clinical patients, both adults and children.

These examples of applications are included here to demonstrate the immediate benefits of an active flight research program and that continued support of such programs in biology can be expected to result in further advances in the developing medical sciences.

That concludes my statement, Mr. Chairman.

Mr. KARTH. It is too bad that last Biosatellite F was canceled; wouldn't you agree with that, Dr. Reynolds?

Dr. REYNOLDS. I am afraid speaking personally I would have to agree with you, Mr. Chairman.

Mr. KARTH. Did you support that decision?

Dr. REYNOLDS. I, of course, ultimately supported it. I must confess I argued against it in the course of the discussion.

Mr. KARTH. Mr. Mosher.

Mr. MOSHER. I don't have any questions at this time.

Mr. KARTH. Mr. Vander Jagt.

Mr. VANDER JAGT. No questions.

Mr. KARTH. Mr. Pettis.

Mr. PETTIS. I would like to wait for the rest of the committee to ask questions on this particular point, because mine is peripheral. If you like, however, I would ask a question.

Mr. KARTH. Proceed.

Mr. PETTIS. Do I understand that the animal or astronaut has to attain weightlessness before what we have been talking about here is pertinent?

Let's assume 50,000 feet. Is there any difference between sea level and 50,000 feet?

Dr. REYNOLDS. No, sir. Most of the effects I was referring to are effects due to change in hydrostatic pressure in the circulatory system and between the circulatory system and other fluids of the body, the tissue fluids of the body.

Mr. PETTIS. For example, body rhythms, say, in just normal airline flying would be affected; so those factors certainly you can't eliminate.

Dr. REYNOLDS. No, sir; that is true. I was referring here to the changes in the circulatory system and fluid balance when I said weightlessness.

Mr. PETTIS. None of these factors would be in existence in space travel because space is anything after you leave the ground, I suppose, or sea level, but at what point do these factors begin to have an effect?

Dr. REYNOLDS. Some of these effects are produced to a small degree by bed rest in man, by lying flat on your back, in that you are decreasing the hydrostatic pressure on the circulatory system by changing the direction in which the gravity is exerted.

Another way of influencing this hydrostatic pressure change is by total immersion of the body in water. In general, the immersion in water appears to have even more severe effects than the weightless environment does in this respect.

However, in order to get measurements of the effects of weightlessness itself and the combination of weightlessness with other factors such as exercise and changes in fluid balance is in space flight.

Mr. PETTIS. Mr. Chairman, may I ask one final question.

It would appear—and I did a little research on this before I came to the meeting this morning—that some of the things you have described as having happened to this monkey and to the astronauts in deep space do also happen to people who suffer what is commonly called jet lag. Some of these very same descriptions that I find in your script this morning—central nervous system effects, cardiovascular and metabolic systems which are affected by body rhythms, functions of the organs—you now find being reported in the medical literature for people such as airline pilots.

So what I am really asking is, is there anyone in NASA or anywhere else making any study of this at levels lower than what you would call space?

Dr. REYNOLDS. There is under discussion at the present time a program to study the effects on man and animals of geographical translation from one point to another, 6 hours or so in time zones. Some work of that nature has been done in the past. It is frankly rather difficult to control in the case of human studies and there has not been, frankly, as much interest as one might expect in exposure of animals to these geographic shifts.

The experimenters that are interested in this subject are more interested in removal of the animals, at least for the animal studies, from the earths environment completely by orbital or heliocentric flight more than they are in geographic shifts. The geographic shift problem does have quite a significance, of course, for aeronautics. I agree that such studies are desirable and the comparison between the results of geographic shifts and space flight is in itself, I think, a very interesting subject.

Mr. PETTIS. I just would like to make this observation. Not many of us are going to be involved, in the human race, with what we are describing here out in deep space. But an awful lot of us get involved in this other problem, in fact millions of us. I just computed that I spent some 21 days in space airflight myself last year, and I was just wondering what these effects are on a human being who does a lot of flying in space but not deep space as you refer to it.

Dr. REYNOLDS. Well, the geographic shift problem is one that is of great interest. Certainly one of the factors that changes is the periods of light and darkness and we know that changes in this period of light and darkness do have rather profound effects on people and on animals and plants.

The mechanism by which this has its effect is not known, and this is one of the reasons for the experiments, to try to learn more about the basic mechanisms that control these cycles.

Mr. MOSHER. Mr. Chairman, can I just break in out of turn. I do have to go to another meeting.

Do I assume correctly that one of the basic questions that must bother us at these hearings is a concern over the coordination of events, so to speak? I assume we have to be worried by the fact that we will be authorizing, or asked to authorize, huge capital investments in the shuttles and various other projects well in advance of any biological results we can get from the space station experiments, and well in advance of any conclusive biological evidence on some of these questions.

Isn't that true? Isn't that a matter of timing? Doesn't that have to be of great concern to us?

Mr. KARTH. I would say to the gentleman from Ohio that I think that is the primary purpose for which the chairman, Mr. Miller, asked us to undertake these hearings. I would assume that if the question of doubt is serious enough as to the effects of long weightlessness on primates and the potential seriousness of it on man it may well be that sufficient cautionary flags be raised so that we may not proceed quite as rapidly as we would otherwise in extended manned space flight. Or at least we might undertake more serious investigation of these questions we do hold in doubt as to the effects of long duration space flight on man. I think the gentleman has stated it properly. I would hope that would be one of the things this committee would be interested in.

Mr. MOSHER. I wish I didn't have to leave, but I hope your questions will bear on that subject.

Mr. KARTH. I will keep it in mind.

Mr. Koch.

Mr. KOCH. Dr. Reynolds, obviously the testing done to the astronauts in all of their missions couldn't possibly be the same kind of testing that has been done on the monkey for the obvious reasons. But is there available to the committee—or perhaps you already have fur-

nished it and I haven't seen it—a detailed listing of all of the adverse effects on those engaged in the program which would in some way indicate to us in a way comparable to that which we now know about the monkey the same effects upon man? Is there such a listing available to us?

Dr. REYNOLDS. There are quite a large number of reports that contain this information. It is my understanding that a summary of this kind of information will be transmitted to this subcommittee by General Humphreys when he is a witness here next Monday.

Mr. KOCH. Preliminary to that, would you be able in a very brief way to indicate whether there had been any gross adverse effects upon the astronauts, any one of them, involved in our program?

Dr. REYNOLDS. I would say that the effects that have been observed that I am familiar with would not be what I would call grossly deleterious effects. There are results that indicate that some of the processes that we saw in this monkey are going on in man. However, they have not shown, at the flight durations that have been flown, that is, up to 14 days, effects that are grossly damaging to the man.

Mr. KOCH. Just one other question in that same area.

Mr. KARTH. May I just interrupt the gentlemen. You are very careful in using these words "grossly deleterious." Counsel points out they didn't die. We are grateful for that.

Would you just amplify on what deleterious effects we do know occurred in the astronauts? The only thing we can find, frankly, in the pocket statistic book or anything else, is they developed colds and, of course, there is nothing too serious about that. We haven't been able to correct it. Everybody catches colds. I would like to have you, for the record, describe in detail, if you will, either now or after Mr. Koch completes his questioning, or at a later date if you are unable to do so now, what these effects are.

Dr. REYNOLDS. I would believe, Mr. Chairman, that the summary report that General Humphreys has prepared will do this in a much better fashion than I can. The observations on man that had been of particular interest to me, have been the weight loss, the evidence of——

Mr. KARTH. Which killed a monkey, eventually.

Dr. REYNOLDS. Factors related to the weight loss in which the weight loss is an indicator were responsible for the monkey's deterioration. What killed the monkey is perhaps another problem, because the monkey had gone through a very strenuous recovery cycle, and he was still in the process of recovering from his decreased body temperature as well, at the time that he went into cardiac failure.

So I don't think we could say the animal was killed specifically by this weight loss.

Mr. KARTH. But the total effects of prolonged weightlessness.

Dr. REYNOLDS. And the recovery process and the low body temperature and the fact that he was in the process of rewarming after having had a low body temperature may have a very important role in the eventual death of the animal.

Mr. KARTH. Are you prepared to describe, for the record, at this point, the deleterious effects we know occurred on the astronauts?

Dr. REYNOLDS. I can mention——

Mr. Karth. I am willing to accept the authority that Dr. Humphreys will add to this question, but I would also like to have your knowledge on it.

Dr. Reynolds. I would prefer to let General Humphreys speak to that.

Mr. Karth. I prefer not to, because I have a great deal of confidence in your ability, too, so if you would prepare completely for the record—what your information is on this deleterious effect, the committee would be most appreciative.

Dr. Reynolds. All right, sir.

(The material requested follows:)

I must preface this statement with the caution that each observation noted here is based largely on published flight medical reports. Without confirmatory experience or experiments these hazards must be viewed as speculations.

1. Nausea—The recent reports of nausea by Apollo crews, coupled with similar difficulties reported by the early cosmonauts, indicate problems in the very sensitive vestibular mechanisms which are involved in balance and provide active control in virtually all coordinated movements.

2. Weight loss—The extensive loss of body mass despite the normal fluid and caloric intake suggest potential difficulties as seen in Biosatellite III associated with dehydration. Unless the mechanisms for weight loss are clearly understood, it may be difficult to ameliorate this hazard.

3. The difficulties with regard to sleeping which have often been reported could potentiate problems associated with inattention, lack of alertness and poor performance. More research into the effects of the space environment on circadian rhythms and the central nervous system coupled with a reduction of the operational requirements on the man may offer solutions for decreasing this hazard.

4. The decrease in red cell mass in the blood coupled with the apparent increase of destruction of red cells by the spleen, though partly attributable to the oxygen rich atmosphere, must not be assumed solvable by a change in atmosphere. The contributions of the water loss and change in cardiovascular function must be considered as additional potential contributors.

5. Demineralization of the bones and its potential for weakening of the skeletal structure should be carefully monitored. Continued degradation with increasing durations of exposure possibly portends severe problems associated with heavy work and particularly with the increased accelerative forces returning to Earth.

6. Reported difficulties associated with high levels of exertion require extensive study. This is particularly true, when considered in relation to the fact that exercise is proposed as a means of ameliorating musculo-skeletal problems.

7. Cardiovascular deconditioning on return to the gravity field suggests changes in the circulatory system in weightlessness which require an increased effort in ground-based and flight research programs on both man an animals.

Finally, I would like to point out that these are merely elements of an integrated problem. Each of these factors is viewed here as an isolated phenomenon, but, in fact, the combination of these effects provides new stresses on the system which in some cases may very well cause them to be more hazardous. An example of this might be a change in the reaction of man to infection or in his tolerance for medication.

Thus experiments with sub-human primates seems a very prudent measure to answer the question of long-term adaptation to weightlessness, a question to which the available data on man does not provide an answer.

However, this does not mean that the present program for the Saturn Workshop should be delayed, but rather the Workshop opportunity should be used to gather the needed biomedical data from animals as well as man.

Mr. Koch. I have two questions remaining. One is, are any of the astronauts now continuing to suffer from any adverse effect which might have occurred as a result of the space flight?

Dr. Reynolds. No, sir; not to my knowledge. I can say as far as I am aware that none of these deleterious effects have lasted more than a few days after recovery and return to earth.

Mr. KOCH. Would it have been helpful to have two monkeys going up at the same time? Is there an element of companionship that enters into this situation so as to make it more deleterious if you are alone in this spaceship?

Dr. REYNOLDS. Our studies on this subject—and they have been conducted—have not led us to think it would be of any advantage to have two animals for the purposes of social communication. It would help greatly scientifically to have more than one animal in making the observations.

Mr. KOCH. The element of companionship—that misery loves company—doesn't enter into it?

Dr. REYNOLDS. Apparently not.

Mr. KOCH. Thank you.

Mr. KARTH. Doctor, on page 4, in the middle of the page, you say:

> However, the principal indicator of the operation of the reflex mechanisms, namely the blood pressure in the veins near the heart, could not be observed in man because of the hazards associated with its measurement. The only existing way by which this measurement could be performed is by the implantation of catheters.

Et cetera.

How important is this in determining the effects that we seek to determine upon an astronaut, or any other human being, that might be subjected to prolonged periods of weightlessness?

Dr. REYNOLDS. I think the demonstration of this effect in the monkey is a quite good indicator that this phenomenon has, in fact, occurred in man. We would like to have any experimental result repeated, but it seems to me one can have a pretty good level of confidence in this particular observation.

Dr. Meehan, I hope, will be speaking to that tomorrow.

Mr. KARTH. How would you categorize that particular experiment? One of importance? One of criticality? One of just mild importance?

Dr. REYNOLDS. I would call it critical, a critical experiment, in that it is a measurement made that is very crucial to a whole body of theory from which one would predict this event to occur. It was measured and it occurred as predicted. I think you would call that a critical experiment.

Mr. KARTH. At the bottom of page 5, you talk about laboratory analysis, et cetera, and in the last two lines, you say, "however an indication of considerable loss of muscle and perhaps other body tissues during flight."

I wonder if you could elaborate on that and tell us how serious you think this to be and would you also categorize that as a critical experiment that ought to be conducted?

Dr. REYNOLDS. Yes, sir, this was in the area in which the in-flight measurements fell below the calibration range of the instrument and the postflight measurements could not totally be completed because of the demise of the animal.

However, it seems to me it is a very important set of measurements and one that certainly should be included and hopefully satisfactorily completed in future flight experiments.

The observations that were made here were based on two factors which I presume Dr. Pace will go into in more detail tomorrow: namely, the change in potassium level in the body as a whole, and in

the proportion of these substances, creatine and creatinine, in the small amount of urine that was retrieved after flight.

Mr. PETTIS. Mr. Chairman, may I ask a question?

Mr. KARTH. Yes, Mr. Pettis.

Mr. PETTIS. Back on page 3, the last paragraph:

> These theories state that the most important physiological effect of zero gravity is the reduction in the weight of the long columns of blood in the body. This weight reduction results in reduced pooling of blood in the extremities.

I imagine the extremities mean the head as well as the feet.

Dr. REYNOLDS. Sir, in this case, it refers mostly to the legs and arms.

Mr. PETTIS. Not the head?

Dr. REYNOLDS. No, sir.

Mr. PETTIS. So there would be no deleterious effect as far as cerebration is concerned?

Dr. REYNOLDS. This is a rather complex subject, but the regulation of the amount of blood flowing through the vessels of the head is a somewhat different regulation than that of the rest of the body, and is under more precise control. I don't believe there is any evidence of a shift in the amount of circulating blood to the head under these conditions.

Mr. KARTH. How long will it take to completely evaluate the data that we received from the primate flight? It has been going on for some time now.

Dr. REYNOLDS. I would guess it will probably be going on for another year.

Mr. KARTH. Do you attach any great importance to that data that has not yet been evaluated that we have not yet had answers to?

Dr. REYNOLDS. Yes, sir. I think, for example, that a part of the evaluation of this data will be based on ground-based studies of animals following up some of the results that were obtained in flight to try to simulate specific things that can be simulated on the ground. I would expect these to be very important insofar as they may confirm some of the explanations that I discussed earlier of the affects of weightlessness on the cardiovascular system and on the nervous system.

Mr. KARTH. Without these answers, Doctor, a cautious medical man probably would not proceed with even a 28-day manned flight. Would that be a fair assumption for me to make?

Dr. REYNOLDS. No, sir, I don't believe so. It seems to me that the principal value that the animal experiment has is in pointing out and confirming the areas that should be watched in manned flight. The actual quantitative assessment of the effects of flight in man must be performed on man. There is no other way to get at it. What you get out of the animal flights is an understanding of the mechanisms involved that you can't do very well in man because these measurements are hard to do in man. They also give you information on useful measurements to make in man that will enable you to quantify his reaction to the environmental change.

Mr. KARTH. So, for the 28-day flight, you don't feel there are any big changes we are taking insofar as it relates to the health and the welfare and the well being of the astronauts?

Dr. REYNOLDS. Not with the plans to monitor him carefully, to utilize some methods that have been developed for ameliorating the ef-

fects of weightlessness, and to provide a quick response in recovery in the event difficulty should intervene.

Mr. KARTH. But for long duration space flight, you wouldn't suggest we spend hundreds of millions or even billions of dollars doing developmental work on a program of that kind prior to getting the answers we feel are so important on the 28- or 56-day flights; would you?

Dr. REYNOLDS. I think it is very important for us to learn as much as we can about the physiological reactions to weightlessness, not to find out whether we can fly for a long time, but to find out what the mechanisms are we must use in order to provide for the long-term manned flights.

I personally have little doubt it will be possible for man to fly for long periods. My question is, what are the procedures and equipment and so forth that we must use in order to make such flights.

Mr. KARTH. I think I would agree with that.

Mr. KOCH. Mr. Chairman.

Mr. KARTH. Mr. Koch.

Mr. KOCH. I find it hard to accept, Dr. Reynolds, your statement that you would not wait to have all of the scientific data which is within our power to have within a fixed period of time coming out of the monkey experiment before proceeding with a 28-day trip for astronauts. And you then say the only way we can find out how these things happen with respect to man is to put man in that setting.

If that were so, if that were the only way, and if, in effect, you are going to use the astronaut for experimental purposes really, then we didn't have to have the monkey in the first place. You have gotten some of the information. You haven't gotten it all.

Why would there be resistance to getting at least all of the information from that monkey experiment, and why wouldn't it make sense to have whatever other experiments were necessary on animal life before we did risk adverse effects upon men that we might send there without having all the other material analyzed?

Dr. REYNOLDS. Well, the opportunity will be available to the men that are in flight during the 28-day mission, if it should be necessary, to recover them earlier than that.

Mr. KOCH. That is the thing I think you are banking on. You are saying, if they go to 14 days, this is OK, and if on the 15th day we see suddenly something adverse occur, we bring them back home. That is really what you are saying isn't there a great element of danger that when something so adverse occurs that it could happen in a very relatively brief moment so that it is past the point where it may be an inrreversible effect on them in terms of its effect upon them physically? And then it would be too late. What is the harm in analyzing all of the data before you send them up there?

Dr. REYNOLDS. Of course, there are a number of hazards in manned space flight. I would say that the hazard of this kind of a situation, that is, the situation you described, would be very much smaller than many of the other hazards associated with manned flight when there is opportunity to monitor the man's physiologic condition and when the results that we have had of flights up to 14 days have not indicated any serious deterioration of the man's physical condition.

I would not feel that the 28-day mission is an unacceptable hazard. However, this is a matter of medical judgment. I am not a medical man.

The space medicine division does have that responsibility but I am saying here that, to the extent I am qualified, I agree with them.

Mr. KOCH. Just one followup question on that. What would be your best estimate as to the time that would be involved in processing the balance of the data yet to be analyzed and is that predicated on an 8-hour day or a 24-hour day in terms of analysis?

Dr. REYNOLDS. Well, sir, I gave you a rather horseback guess. We had originally planned to allow the experimenters a 6-month period for exclusive use of the data; that is, use they had of the data before this was made available for other investigators to also use. That period would be up sometime in January. It might be in view of the postflight tests that are required we will be requested to extend that period of exclusive use. We have not had such a request. I think that after that period of exclusive use is over the data will continue to be analyzed by these investigators as well as others for a long time. There is a great deal of information that has been collected, and I would feel that it will probably be a year before the postflight studies on the ground and the flight data have been correlated so that something approximating final reports will be coming in.

Mr. KOCH. Is that an 8-hour day or a 24-hour day in terms of analysis of this particular data coming out of the monkey experiments?

Dr. REYNOLDS. I imagine that varies in the different laboratories. It is probably closer than an 8-hour day, but you remember a lot of this is mental activity on the part of people which you can't really do very well on a 24-hour-day basis. I am sure as far as computer activities are concerned they are probably available for much longer periods.

Mr. KOCH. Thank you.

Mr. KARTH. Mr. Koch and I are going to take turns disagreeing with you. Ever since we have initiated the manned space flight program, from an engineering standpoint I have been told that manned space flight is 99.966 fail-safe. That leaves very little chance for accident. It had to reach that fail-safe level before we would launch man into space.

Are you saying to me, to this committee, for the record, that as far as the one thing that the engineers have not provided for—that is the results or the effects of long-term weightlessness and other space flight phenomena that could take place—is at least 99.966 fail-safe? That there is no more doubt in your mind as to the deleterious effects than 99.966?

You really can't say that, Doctor, can you?

Dr. REYNOLDS. That is a matter of medical judgment and I don't think I am qualified to answer that question.

Mr. KARTH. But you see, the engineering judgment that has been made has been made on the basis of a proliferation of tests on the ground and in space without man being associated directly with it. We don't have this kind of experimentation so far as it relates to his well-being due to the phenomenon of space and the adverse effects. I guess you couldn't possibly say you feel 99.966 percent sure that these effects, these deleterious effects, will not be serious or be harmful to a point where we ought to do considerable more than we have done up to this point before we can feel sure. You can't say that, can you?

Dr. REYNOLDS. I could not say I would feel we had that percentage of chance. that the 28-day mission will be completed without observing some effects that will call for early recovery.

Mr. KARTH. You didn't mean that when you said there are other hazards that are more dangerous to the health and well-being of the astronauts than this one we are investigating today. You can't really say that, can you?

Dr. REYNOLDS. I think I can, if we allow the other factors that I mentioned; namely, the continuous monitoring of the individual and the opportunity for an early recovery.

Mr. KARTH. On the basis of what we know, due to our previous experimentation and the safety factors that have been built into manned space flight, on this subject we are discussing today, we do not approach 99.966 percent fail safe, do we?

Dr. REYNOLDS. I am afraid I would not be willing to assign that degree of certainty to any physiologic event. There is too high a percentage. I am not that sure of anything.

Mr. KARTH. So you are not as sure as the engineers are about the fail-safeness of the vehicle from a performance standpoint of the man-made paraphernalia that is there to take care of the astronaut in terms of seeing he gets there and gets back in one piece.

I can understand your reluctance to assign that degree of certainty.

Mr. Pettis.

Mr. PETTIS. Are we maximizing the testing on the physiology of the astronauts in the upcoming Apollo 12 mission in terms of some of the things that have been talked about here today?

Dr. REYNOLDS. Not to my knowledge, no sir; but I think this is a question that the representative of space medicine will be able to answer better than I.

Mr. KARTH. Mr. Vander Jagt.

Mr. VANDER JAGT. You base your confidence on no adverse effects on the astronauts in space on two factors, as I understand it. One is the constant monitoring and the other is ability for quick recovery. Now, both of those factors were present in the case of the monkey and we lost the monkey.

Dr. REYNOLDS. We didn't have the ability to follow the body weight change and quite frankly we were at that time not as aware of the problem, of the seriousness of this water loss problem, as we now are. I think that this has certainly—the Biosatellite III flight—focused a lot of attention on this problem which I am sure will affect the way in which monitoring of astronauts in long-term flight will be conducted.

Mr. VANDER JAGT. In many ways the monitoring of the monkey was far more extensive and complete than you would ever hope to achieve for the astronauts.

Dr. REYNOLDS. Yes; but not for these factors. The experiments were designed to look for other things. I think it is interesting to note that the blood pressure and heart rate and other vital signs like that stayed in very good condition right up to the time that the deterioration became very severe.

Mr. VANDER JAGT. Isn't it possible, just as we overlook some factors in the case of the monkey, we could be overlooking some significant

factors in the case of the astronauts if we don't have the results of these extensive tests?

Dr. REYNOLDS. I think that the amount of evaluation that has been given to this problem by ourselves, by the Space Science Board Committees and so forth makes the probability of a completely unexpected kind of a phenomenon rather small. The quantitative effect of this, I think, is what surprised us in the monkey and we have quite a bit of information on manned flight in the past. There have been 20 or more astronauts that have flown and this is the first monkey that was flown for a long period.

So I think the effect of surprise in this kind of a range is much greater in the first case as with the monkey than it would be after having had a lot of experience with manned flights.

Mr. PETTIS. Mr. Chairman.

Mr. KARTH. Mr. Pettis.

Mr. PETTIS. I would like to ask the doctor this. There are obviously some tests you would not want to do on any of the astronauts that you would do on the monkey, correct?

Dr. REYNOLDS. Yes.

Mr. PETTIS. That is a constraint of one kind.

Dr. REYNOLDS. Yes, sir. However, I think the weight loss, the water balance changes, can be followed. It will be possible on the basis of postflight analysis of urine collected to use the 28-day mission to decide about what the safe limits are for the following longer missions. So, I think the 28-day mission is really quite crucial to our really understanding the quantitative effects of these environmental situations on man.

Mr. HAMMILL. When is that scheduled to fly, Dr. Reynolds?

Dr. REYNOLDS. As I understand it, 1972. I don't think there is a more precise date than that that I am aware of.

Mr. KARTH. Mr. Koch.

Mr. KOCH. I would like to pursue the question of my colleague because I thought it was really first rate to point out to you that when you were able to bring the monkey back you didn't in time to save its life really. And my recollection—I think it is correct—is that there was even some discussion as to whether he ought to be brought back, or not be brought back, and ultimately you made a decision to bring him back, and it wasn't an instantaneous decision based on mechanisms you were monitoring. So there is human error as to when to bring them back, the monkey or the men.

What is also interesting to me and by way of observation is even your calibrators from your testimony weren't sufficient to monitor the situation. If I understood it correctly, you weren't able to actually correctly calibrate one of the tests because whatever the monitoring system is it didn't provide sufficiently—I don't have the expertise to describe it—didn't provide sufficient depth below which it could fall so as to monitor what the situation actually was. Isn't that a fair statement?

Dr. REYNOLDS. That is true of three of the sensors actually.

Mr. KOCH. God forbid that would occur when we have men in flight and, therefore, what I really am trying to find out is why doesn't it make more sense to have another monkey or a third or a fourth monkey in flight and to complete the analysis of all of the data

which you say hasn't been analyzed before we undertake to place man in jeopardy?

Why is it so important the man be placed in jeopardy? There is a certain jeopardy even if everything went well. Why is it necessary to put them in that jeopardy without having exhausted all of the possibilities within our power?

I recognize ultimately when they are up there there is going to be danger. We recognize that. Why can't we exhaust all of those things within our power? What is the rush?

Dr. REYNOLDS. Of course, what I would like to see is some additional primate experiments and, frankly, it looks to us as if the best environment in which to conduct these experiments would be in the Saturn workshop in connection with the 28-day manned mission. Whether that is too close a schedule and it may not be possible to do that, I don't know. But we are studying that possibility. Certainly we feel that somewhere in the space workshop and space station program we should get further primate studies, and I would be in favor of achieving these as early as is possible.

Mr. KOCH. Before we send the men up?

Dr. REYNOLDS. No, sir. As a matter of fact, one of the advantages is the opportunity to have these experiments tended by man and some of the kind of measurements we would like to make can be much better achieved with a human operator in attendance.

Mr. KOCH. One last question. You think the risk is worth taking of sending men up to be the subject, really, of the experiment because that is really what we are talking about, the effects upon them directly—that that is worth taking rather than to have an intervening experiment on primates? Isn't that what you are saying? You think the risk is worth taking and, therefore, you would not wait to have the experiments made on the primates in advance of sending them up other than the one experiment which we just discussed, which has been a failure in a way because that animal is dead.

Dr. REYNOLDS. Yes, sir, I believe I can agree with that, with your statement.

Mr. KOCH. It is not my conclusion. Did I state your conclusion correctly?

Dr. REYNOLDS. Yes.

Mr. KOCH. No further questions.

Mr. KARTH. Doctor, we have another witness and I have a speech to make at noon today on the space program. I don't want to miss that. I have a couple of other questions I would like to get over with quickly, if I could.

Was there any red cell mass loss in Bonnie?

Dr. REYNOLDS. We cannot tell that because in the process of trying to recuscitate the animal he was given a whole monkey blood transfusion and other fluids which would make it pretty difficult to determine changes in red cell mass. If we had been able to complete the post-flight experiments, we would have had the answer to that question. We don't have it.

Mr. KARTH. Just two quick questions.

Recently, in fact last week, and I assume because of Dr. Adey's findings, there was an announcement by NASA they had ordered a study of space flight biomedical experiments required to determine the qualification of man for long-term space flights.

What is implied by the expression, "qualification of man?" Does this imply demonstration of a mere ability to survive in space for protracted periods or does it involve also the demonstration of continuing high levels of physical and mental performance? Do you know?

Dr. REYNOLDS. Sir, I kind of don't much like the use of the term, "qualification of man." I think this term was developed to try to put the development of man in the context of the engineering system where they do qualification tests in advance.

Mr. KARTH. It is NASA's term. That is why I am forced to use it. I do wonder what they mean by it. That is what I am asking.

Dr. REYNOLDS. I don't believe it was initially NASA's term, Mr. Chairman.

Mr. KARTH. Really?

Dr. REYNOLDS. My feeling is if one is going to use that term it should be in terms of performance, not of survival. If man must serve as a part of a space system in performance, then to qualify him must mean to qualify him to perform at the level expected of him.

Mr. KARTH. Irrespective of whether the term originated at NASA, I certainly agree with your answer to the question.

I had hoped to be able to ask you a few additional questions, Dr. Reynolds. Due to the press of time, however, I will simply submit the questions to you, and make your answers part of the record of the hearings.

(The written response of the witness follows:)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION,
Washington, D.C., December 11, 1969.

Hon. JOSEPH E. KARTH,
Chairman, Subcommittee on Space Science and Applications, Committee on Science and Astronautics, House of Representatives, Washington, D.C.

DEAR MR. KARTH: Thank you for your letter of 18 November 1969 affording me the opportunity to provide additional information for the Subcommittee on Space Science and Applications. The questions in your letter and my answers follow:

1. Do you feel that further unmanned biological experiments are essential? Desirable?

I believe that further biological experiments in space flight are essential if this country is to make the most effective use of its leadership in space technology. Also it is inconceivable to me that long-term manned flight will be achieved without animal experiments in space as a means of understanding the biological effects of the space environment on man.

It may be desirable to conduct some of these experiments in unmanned systems, where the required mission profiles are hazardous or uneconomic for manned flight, or where the presence of man prejudices the scientific value of the experimental data.

2. What specific plans does NASA, or does your office, have to accomplish these?

Four experiments, one on cell growth in human tissue and culture and three on circadian rhythms are planned for flight in the AAP program. One experiment on the effect of weightlessness on the organ of balance of the frog is scheduled for flight in a Scout launched spacecraft in 1970. Experiments have been proposed for the Second Saturn Workshop and the Space Station. In addition we have proposed automated bioscience research in Explorer, Pioneer and Biosatellite class spacecraft. None of these latter proposals are approved at this time.

3. Are you content with the status of these plans? Do you feel there is adequate assurance that such experiments will be conducted?

No. We have in hand a large number of scientifically recommended experiments, some of which are in an advanced state of development, but there are no approved plans for unmanned flight programs in which these experiments can be conducted, and the Orbital Workshop Program has very limited funds for experiment development.

4. What would be the best way to accomplish the experimental program you feel is necessary?

I feel we should incorporate sorely needed opportunities on automated recoverable and non-recoverable spacecraft systems for the acquisition of biological data and which take advantage of manned flight opportunities as available. The unmanned systems should include improved Biosatellites, and non-recoverable Bioexplorers and Biopioneers all of which afford unique capabilities and economies not available on the science-limited manned spacecraft. The man-tended experiments would begin with the first Saturn Workshop by adding to the present plans a primate cardiovascular and metabolic experiment and would include more extensive biomedical monitoring of similar functions in astronauts. In summary, I feel we should maintain the capability developed for the Biosatellite on missions best accomplished on automated flights and maximize the participation of biomedically trained science astronauts in manned missions.

5. How do you view the cancellation of the Biosatellite Program?

The Biosatellite Program of six flights was planned to provide a "survey" of the type of biological effects that might be expected to be encountered in the space flight environment to bring out the areas deserving of further study, and to provide confirmation of the results by second flights. From the three flights we have gained valuable insight in definitions for future flights, but we should continue the survey approach to take advantage of newly emerging concepts.

Though I do not at present favor the reinstatement of the particular cancelled Biosatellite Flights, I strongly favor the institution of new programs for biological flights in this automated type of system.

Please let me know if I can be of further assistance to the Subcommittee.

Sincerely,

ORR E. REYNOLDS,
Director, Bioscience Programs,
Office of Space Science and Applications.

Mr. KARTH. I would like now to proceed to Mr. Dyer, who is the operations manager of the biosatellite program at Ames Research Center.

Mr. Dyer, would you proceed, please.

STATEMENT OF JOHN W. DYER, OPERATIONS MANAGER, BIOSATTELLITE PROJECT, AMES RESEARCH CENTER, NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Mr. DYER. Mr. Chairman and members of the subcommittee, the Ames Research Center has management responsibility for the biosatellite project. The Biosatellite III Mission Director, Mr. Charles A. Wilson, is also here today should you require further commentary. This presentation is to briefly describe the Biosatellite III spacecraft and its flight operation. Biosatellite III was recovered on July 6 from orbit after 8½ days of flight.

The spacecraft was designed to accommodate a monkey in shirt sleeve environment with standard nitrogen and oxygen atmosphere, controlled temperature and relative humidity, and designed to move through space with accelerations due to its rotation typically less than one one-hundred thousandth of gravity. That means a rotation of the spacecraft was no more often than once in 20 minutes.

The structural configuration, the separation, reentry, and recovery systems were the same as were flown for Biosatellites I and II. Separations are shown in figure 1 on your handout.

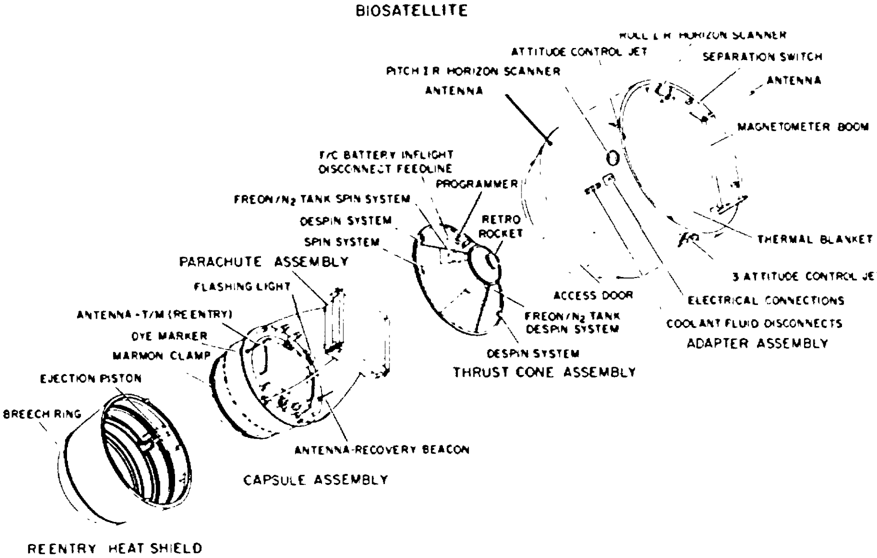

Figure 1.—Structural separation of biosatellite spacecraft.

For the primate mission, however, the power supply was hydrogen-oxygen fuel cell designed to provide 130 watts of power at least for 30 days. The water produced by the fuel cell, which totaled about 3 pounds a day, was used for drinking by the animal, for capsule humidification, and for expelling heat through an exaporative boiler built into the spacecraft.

Provisions were incorporated into the environment control system to remove contaminant gases, carbon dioxide, excess humidity, and, of course, to maintain the partial oxygen pressure. Total capsule pressure would have been made up by a supply of compressed nitrogen had the capsule leaked during flight.

Other major design considerations included a pellet feeder which was to be reliably operated by the animal for up to 30 days, a provision for drinking water in weightlessness, a provision for measurement and removal of urine to a waste storage tank, and a kind of pneumatic transfer of feces into a storage can.

The tracking, telemetry, and control system was designed to be compatible with Goddard's Space Tracking and Data Acquisition network, the same as for previous flights.

The telemetry carrier accommodated 10 channels of brain waves with responses to 30 cycles per second, six channels of blood pressure, two channels of electrocardiogram, and two channels of electromylogram, along with more than 100 channels of equipment performance data. Total rate was 22,400 binary bits per second.

The spacecraft (figure 2 of the handout) was designed and developed by the General Electric Co., Reentry Systems, Philadelphia, Pa.

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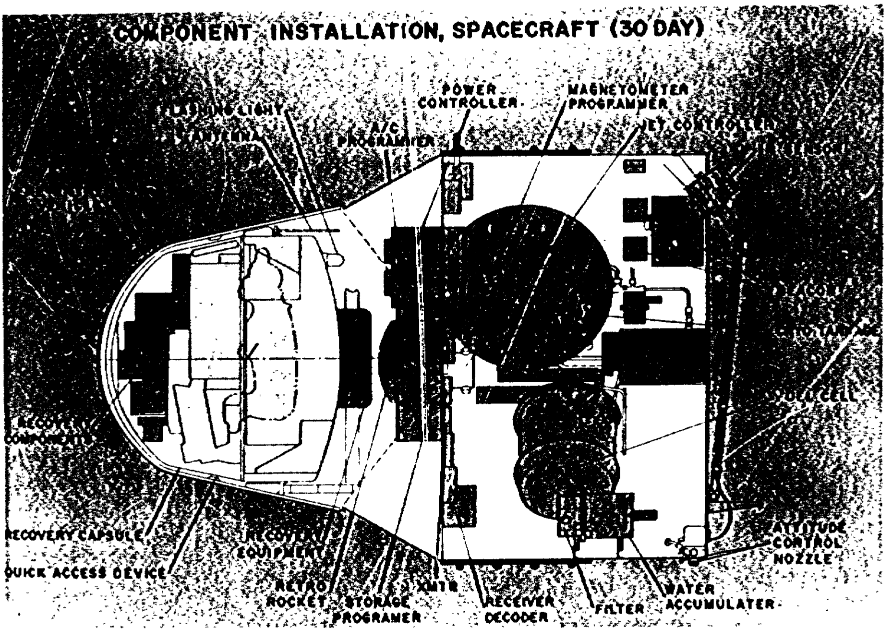

FIGURE 2.—Configuration of biosatellite spacecraft.

Tracking and data participants included British, Australian, Japanese, and Department of Defense stations, in addition to the NASA's STADAN and Manned Space Flight Networks, so that the resulting communications network was the largest ever configured for an unmanned spacecraft. That is the total array of tracking facilities as shown in figure 3.

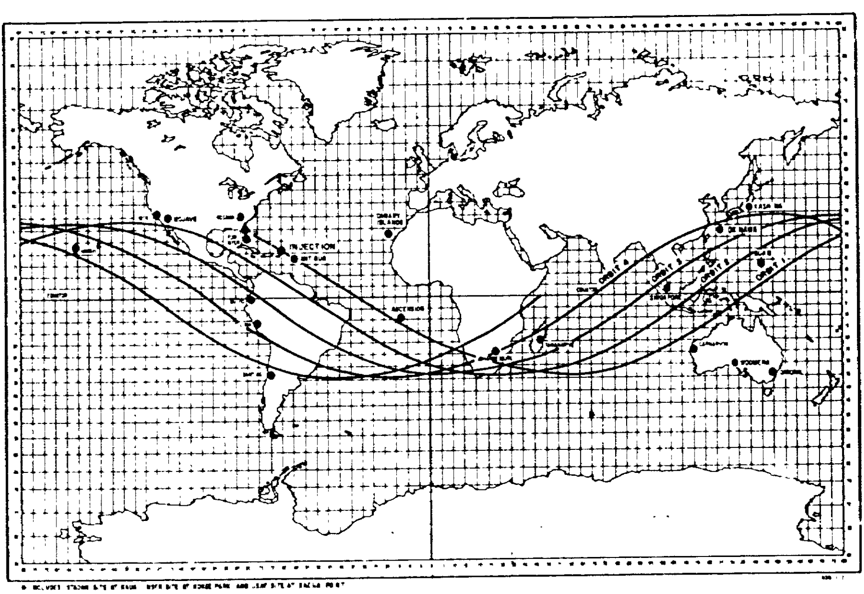

FIGURE 3.—Array of tracking facilities.

After more than 60 days of intense preparations at Cape Kennedy, the 14-day countdown was trouble free for both the spacecraft and the animal with his instrumented couch.

Our mission director, Mr. Wilson, had been prepared with a defined list of acceptable failure conditions under which we would still have proceeded with launch in the final hours. We had particularly recognized the possibility of failure in the very sensitive circuits that measured blood pressure, brain waves, breathing, et cetera, from the 13-pound animal. A chart of interdependencies of value to experimenters had been worked out in advance and agreed upon with them.

So we were extremely pleased when Dr. Adey and his coinvestigators reported before launch that every channel was working and the animal was 100 percent ready to go. Spacecraft data, too, indicated perfect readiness.

At injection into orbit, the data showed only momentary deployment of the magnetometer boom which was to unfold 30 seconds after separation from the Delta launch vehicle, but everything else was perfectly normal. The animal was reported to be very little disturbed and all the biological instrumentation was still in good working order.

As planned at Johannesburg, we transmitted ground commands to stop the onboard camera and enable the evaporative boiler and to back up some of the automatic functions. Over the next three orbits, we enabled several of the equipments which subsequently were operated by onboard programers.

All of the automatically controlled functions performed precisely. The fuel cell was regularly purged with hydrogen and oxygen to prevent accumulation of contaminants in its system. Drinking water was made available to the animal every 3 hours during the night, and every 1 hour during the day (and, incidentally, it was quickly consumed).

The lighting regime, day and night 12 hour sequences, worked perfectly. The camera took pictures every 20 minutes, plus programed intervals of four frames per second cine mode. Attitude rates kept accelerative forces to a very few millionths of earth's gravity.

Capsule temperature tended toward the 70° F. minimum desired, so we commanded, from the ground, a thermostatically controlled heater which protected that limit.

Near the end of the first flight day, in orbit 12, we switched the attitude control system to its deorbit mode and verified that the magnetometer boom was out exactly where it should be, dispelling the earlier doubt.

Several unscheduled food pellets were made available to the monkey during the first flight day. His visual motor task was inhibited in eliminating that problem and a second delayed matching task was offered in its place for 3 days until confidence was regained to go back to the normally programed events.

In general, the spacecraft and all instrumentation performed very well throughout. The animal was reported to be enthusiastically eating and drinking, and after 4 or 5 days, a routine operation capable of going the duration of onboard consumables was projected.

But the animal's condition deteriorated sharply on the eighth day. The Air Force was alerted for possible retrieval as the experiment

representatives on the control team deliberated with the investigators over the advisability of early flight termination.

Analysis of the gas samples from the recovered capsule confirmed that the consistency of the atmosphere had been correctly reported and controlled and that the atmosphere was free of toxicants.

All the physiological sensors, including those attached to the animal with sensitivities down to a microvolt, continued to perform perfectly upon reconnection to recorders in the postflight laboratory after recovery.

The space craft systems still in orbit were exercised without difficulty for a total of 38 days, 30 days after recovery of the animal.

In summary, the Biosatellite III spacecraft proved highly satisfactory, and its mission was effectively supported by all participating agencies.

That concludes my statement, Mr. Chairman.

Mr. KARTH. Thank you very much. Do I assume correctly that your responsibility is primarily engineering of the spacecraft as opposed to the biomedical area?

Mr. DYER. Yes, sir; that is correct.

Mr. KARTH. What was the total cost of that flight?

Mr. DYER. May I have Mr. Wilson or Dr. Reynolds help me with that question?

Mr. WILSON. The total cost of the 30-day program was approximately $90 or $92 million, total flight costs, and because of the cancellation of the biosatellite flight F we are, of course, having to carry the entire cost on the one flight.

Mr. KARTH. Thank you very much, Mr. Wilson.

Mr. Pettis.

Mr. PETTIS. No questions.

Mr. KARTH. Mr. Dickinson.

Mr. DICKINSON. No.

Mr. KARTH. Mr. Hammill.

Mr. HAMMILL. I would like to follow up Mr. Mosher's question, if I may, just before we leave. I will begin by going back to your testimony, Dr. Reynolds, to the effect that you feel confident that men can perform adequately in space for 28 days. But if it turns out in the first workshop operation that there is a practical limit of, say, 25 days, to men operating in space, we won't know that until sometime in 1972 or 1973. But in the meantime we will have invested very, very large amounts in the development of future manned space systems. The Space Task Group report, for example, indicates that the space station which will accommodate up to 12 men should be ready for launch in 1977 and that implies that there is going to be an awful lot of work done to get that ready prior to 1972 or 1973 when the results of this will be available.

I am just wondering whether we are running a risk of investing in something that will prove not to be feasible.

Dr. REYNOLDS. Well, sir, one of the principal purposes of the space station would be to obtain data on man and animals and on the means of preventing any problems we are having with low gravity. For example, the space station design is considering the use of artificial g. There are other methods that are being discussed and will actually be checked out in the workshop such as the lower body negative pres-

sure device which is a method of combating this shift of blood to the chest.

I feel that these methods for extending man's stay time in space will be successfully developed providing the support is available for sufficient work in animals and man in the earlier missions that are being planned. In other words, I think there is a great deal of physiology to learn. We have to learn it by experiment, and experimentation both on man and animal in space is required. The program, as designed, is designed to get sufficient information to prepare for long-term missions.

Mr. HAMMILL. If the investments are made in a space station, they will be made on the assumption that you will have to have an artificial gravity; is that correct?

Dr. REYNOLDS. No, sir. As I said, the designs that are presently being considered give a provision for artificial gravity.

Mr. HAMMILL. Will it add to the cost greatly to produce this kind of system?

Dr. REYNOLDS. I am not prepared to answer that question, Mr. Hammill.

Mr. HAMMILL. That is all, Mr. Chairman.

Mr. KARTH. To the best of my knowledge, all of these spacecraft—the present Apollo spacecraft, the follow-on Apollo spacecraft, the 6- to 12-man orbiting space station—are all being designed for engineering consideration. To my knowledge, there is no effort or at least no obvious effort to design them for biomedical experimentation or purposes. Is that correct?

Dr. REYNOLDS. There are specific experiments being developed both to study the effects of this environment on man and for experimental work on animals in both the workshop and in the space station. As a matter of fact, studies are underway considering various modules for the space station that would be specifically designed for biological experimentation and the medical monitoring systems which are in development will be partly used in the Saturn workshop and will be in its full development for the space station.

Mr. KARTH. Do you know, Dr. Reynolds, what the cost of the equipment for these biomedical experiments will be for the space station?

Dr. REYNOLDS. Not yet, sir. Our studies have not gone to that stage yet.

Mr. KARTH. Do you have any estimate as to what those costs might be?

Dr. REYNOLDS. For the space station?

Mr. KARTH. For the biomedical experiments in the space station as opposed to the engineering costs of development.

Dr. REYNOLDS. No, sir; I don't have that information. The space station design, of course, is in the early stages right now, and I don't think that information has been developed yet.

Mr. KARTH. Are there any other questions?

Mr. PETTIS. Only one, Mr. Chairman.

Would it be possible for there to be some input here from the aeromedical people, both in Government and in industry, on those features that are comparable from near earth space travel and weightless space travel as far as biomedical problems are concerned? Is that possible? I know that a lot of work is being done both in Gov-

ernment and industry as far as the effects on man are concerned in space travel, but we are talking about something where there is not weightlessness.

Dr. REYNOLDS. Yes. Of course, the Aerospace Medical Association has devoted a great deal of attention to this problem of the effects of air travel. I think that it is desirable to know more about the geographic shift problem you mentioned in terms of daily rhythms. Some of the experimenters feel they can best understand the mechanisms of these changes better by other types of experiments including those in space flight than they can by the geographic shift itself.

For example, you can produce one type of shift similar to the geographic shift just by changing the light cycle on a human or an animal that is in a confined environment. It is not dependent on natural lighting.

Mr. PETTIS. Thank you.

Mr. KARTH. The Chair would announce that tomorrow, beginning at 10 o'clock, we will hear Dr. Adey. He will be the first witness, followed by Dr. Pace and Dr. Meehan.

At this point the committee stands adjourned until 10 o'clock tomorrow morning.

(Whereupon, at 12 p.m., the subcommittee was in recess, to reconvene at 10 a.m., Thursday, November 13, 1969, in room 2325.)

THE FUTURE OF THE BIOSCIENCE PROGRAM

THURSDAY, NOVEMBER 13, 1969

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

The subcommittee met at 10:10 a.m., in room 2325, Rayburn House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. KARTH. The subcommittee will come to order.

Today we continue hearings on the future of the bioscience program and we are honored to have with us as witnesses Dr. Ross Adey, who is professor of anatomy and director of the Space Biology Laboratory, University of California at Los Angeles; Dr. Nello Pace, professor of physiology and director of the White Mountain Research Station, University of California at Berkeley; and Dr. Meehan, chairman of the Department of Physiology, School of Medicine, University of Southern California.

First, however, I want to announce that we have just received from Dr. DuBridge, in the Office of Science and Technology of the President, the PSAC report on its study of the biomedical foundations of manned space flight. Since this report has particular pertinence to the subject of these hearings, I am having it printed in the record at this point.

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THE BIOMEDICAL FOUNDATIONS

OF

MANNED SPACE FLIGHT

A Report of the Space Science and Technology Panel

of the

President's Science Advisory Committee

EXECUTIVE OFFICE OF THE PRESIDENT

OFFICE OF SCIENCE AND TECHNOLOGY

November 1969

(37)

THE WHITE HOUSE

WASHINGTON

The United States has achieved, during its first decade in space, significant new capabilities that have opened this vast domain to man and his instruments, permitting a vision of the future in which man may venture into space as routinely as he now does into the air.

The realization of this promise depends not only upon further technological success, such as the evolution of low-cost systems for transportation into orbit and development of long-lifed systems for support of man, but also, and perhaps more importantly, upon understanding of man himself in the space environment.

The Space Science and Technology Panel of the President's Science Advisory Committee has identified the essential characteristics of a new biomedical capability that will be required in order to harvest the true potential that our engineering and scientific skills now make possible. The Panel has pointed the way to creation of this new biomedical capability and has painted an exciting picture of the possibilities that may be realized from its creation, not only for man in space but on the ground as well.

Man has achieved a goal that has been a dream for centuries and has set foot on a heavenly body beyond his own planet. The future may lead us further into space - perhaps to our neighbor planet, Mars. We cannot predict whether or at what time this goal may be achieved. But it is clear that if we are to achieve such a goal, we will require biomedical information of the nature recommended in this report.

I am therefore releasing this report for publication so that the excellent work of this Panel will be available to all as we chart a course into the future.

Lee A. DuBridge
Science Adviser

THE PRESIDENT'S SCIENCE ADVISORY COMMITTEE
EXECUTIVE OFFICE BUILDING
WASHINGTON, D.C. 20506

NOV 1 0 1969

Dear Dr. DuBridge:

When the evolution of technology promises a dramatic extension of man's domain, our imaginations are rarely adequate to foresee the consequences. Human courage, engineering skill and national dedication have demonstrated that men can venture physically into the vastness of space. How will we use this new capability for manned space flight? What are the limits of human performance in this hostile environment? Is it likely that manned flight into space will ever become commonplace?

The Space Science and Technology Panel of the President's Science Advisory Committee has addressed itself to ways in which adequate answers to these questions may be achieved, having regard to current deficiencies in our basic knowledge of the effects of the space environment on virtually all living organisms and particularly on man. We are aware that historically the capability to fly in the air produced a revolution in human affairs of enormous value and importance; the demonstration that man can survive the polar winter and penetrate the ocean depths hasnot yet done so. Further we are mindful that space exploration by man is so unique a capability as to defy the value of historical analogy as a predictor. No other expansion in man's domain has involved so dramatic an extension of volume. None requires so much energy or such elaborate provision for life support. For the first time the distances potentially involved make the speed of propagation of light and radio waves a significant factor in the effectiveness of remote operations.

At the same time the march of science and technology has brought us to the cybernetic age. New developments in the handling of information and of remote sensing and control with computer augumented human intelligence dramatically extend the radius of man's effective presence. Thus man's sensory capability has been taken to the ocean floor to locate sunken submarines and to Mars to examine its surface without exposing man himself to the rigors of either environment.

Since we cannot predict the circumstances that will motivate man to continue ventures into space or the frequency with which he will do so after initial exploration of the moon, the attached report does not envision commitment to any particular manned flight program -- either in terms of launch rate, spacecraft design or mission profile. We do conclude that such manned spaceflight programs should be prepared and

designed to yield reliable information about human performance in space. This will require a very carefully prepared program of ground-based and in-flight biomedical research, placing more emphasis than at present on a broadly based biological research program as a supplement to essential biomedical services directly connected with the flight program.

We feel that a properly conducted research program, although oriented toward space flight, will, over the course of time, yield new knowledge in environmental medicine and bioengineering of great potential social value.

Sincerely,

Lewis M. Branscomb

Lewis M. Branscomb
Chairman
Space Science and Technology Panel

THE BIOMEDICAL FOUNDATIONS OF MANNED SPACE FLIGHT

A REPORT OF THE SPACE SCIENCE AND TECHNOLOGY PANEL

1. INTRODUCTION

NASA, in its first ten years, has committed the majority (61% and $22.3B) of the agency's funding to support of manned space flight. In making this investment the Nation accepted the Apollo manned lunar landing goal and implicitly, the premise that physical access by man to space is a necessary condition to the useful exploration of this domain, as it has been in the past for exploration of the oceans, deserts, jungles and polar regions of earth. NASA is now seeking to define and gain support for manned programs for the post-Apollo period at a time when there is a growing national preoccupation with domestic and international problems. Decreasing NASA budgets have resulted in a reduced Apollo Applications Program, NASA's choice as the first step in post-Apollo manned flight, and have delayed the scheduled launch dates.

NASA's impressive engineering developments, together with those sponsored by the DOD, have given man the ability to venture into space in person and have also produced an important, reasonably reliable, alternative mode of access to space; remotely controlled automated systems.

Thus, now that we are at the threshold of achieving our Apollo goal, and are faced with decisions about the scope and content of our future space program we must consider a basic question common to many other areas of technology: What is the most effective and beneficial combination of man and machines to accomplish our desired objectives?

The dilemma of NASA in seeking a clear role for manned operations in space can be illustrated by modern trends in laboratory research on earth. Here, where man is conventiently available, it is cost-effective to replace man's hands by automated devices, freeing his mind for the uniquely human task of intellectual creativity. On-line computer-control of apparatus, and even its remote operation, are proving more and more effective. Nevertheless, continued availability of a trained scientist ensures system reliability and modernization.

While on earth we can empirically explore varying combinations of men interacting with machines, making adjustments with each new experience, in space we face three grave obstacles to this approach:

1. Access. In the remote and hostile space environment an automated, unmanned system fails irredeemably when it fails to respond to commands from earth. Its shorter mean-time to irreparable failure and its more rapid obsolescence than its accessible earth-bound counterpart both raise its effective capital cost.

2. Cost. Basic costs associated with placing and maintaining man in space are so great that ultimate justification for his participation in space systems--in economic terms--must depend on the quantitative determination of the extent to which the cost of his presence can be reduced.

3. Unique New Environment. Because of resource limitations, before we explore the limits of man-assisted space systems we would prefer a judgment now on the probable outcome of such research. Yet while our experience tells us much about how to build automated systems as well as how to protect a man in space from harm while participating in the system in a limited way, we know very little about possibilities for maximizing man's contribution to total system reliability and performance.

Nor have alternative strategies been properly explored, such as substitution of man's sensory and manipulative capabilities by automated subsystems (often called telefactors), providing at a remote location and in real-time, perception, judgment and control by men who remain on earth.

If we develop in parallel the technology of both unmanned-automated space systems and of man-assisted systems, at what time and on what overall scale of effort might man in space begin to "pay his way?" Perhaps for some purposes, such as the operation of space-applications systems in earth orbit, that day will never come, if the technology of automation and quality assurance continues its rapid advance.

It is possible, of course, to see goals that require man in space, such as the eventual exploration of the planets by man. The 1967 President's Science Advisory Committee report on space goals after Apollo noted that "--the most challenging ultimate objective for space exploration is exploration by man of the nearby planets and the Moon as subjects for exploration, or about the feasibility of a manned voyage of two years duration to permit the assignment of a time frame for its attainment." With reduction of the space budget by one-half billion dollars per year in each of the last three years this time scale is clearly even more remote than it appeared earlier.

Recognizing that the goal of manned planetary flight seems more remote than ever, the question of man's tolerance for 700 day missions seems less important than the question of man's utility in post-Apollo lunar exploration and in providing engineering assistance to possible complex space systems in earth orbit for scientific purposes. For this reason we feel the focus of efforts in manned space flight should be shifted from tolerance for flights of long duration to modes and levels of effectiveness of man-assisted systems on the moon and in earth orbit.

We are convinced that the necessary biomedical foundations for the design of optimum flight programs to explore such questions do not yet exist--either in NASA or in the scientific community at large. NASA, without recognition of the importance of these foundations, and without a major modification in its approach to space biomedicine, will only be able to conduct empirically designed manned programs which promise slow and very expensive progress toward the understanding of man's optimum role and intrinsic capabilities in space.

Why is it important to understand man's role in space and why should NASA modify its approach to biomedicine in a major way?

We will explore these questions in detail in our report. Quite briefly, we believe the persuasive element is cost, not only in terms of expenditures to achieve operational objectives but also cost in terms of potential social benefits that are needlessly lost if manned flight programs continue to be pursued as in the past.

We believe that man will continue to venture into space because of his innate desire to explore the limits of his environment. NASA will respond by defining a continuing series of manned programs, programs that promise to be successful, in the sense that Mercury and Gemini were successful. But these programs--whatever their total cost--will be wasteful if they do not utilize man effectively. They will be most wasteful if they fail to test the relative virtues of manned and unmanned alternatives for all classes of major space objectives.

Major engineering decisions, controlling the character of possible future space stations, logistic systems and other manned spacecraft depend on evaluation of man's potential for useful work in space. Given the present great expense of transportation to and from space, should we expect high level performance for ten days, thirty days or even ninety days at a time? What is the optimum sleep, rest and work schedule? What crew size is optimum? Can we be sure that astronauts are relieved of every task that can be automated or ground controlled so that their expensive services can be put to optimum use? How does this picture change as we lower the cost of transportation to and from orbit? What are the relative failure probabilities applicable to accomplishment of assigned tasks in space for astronauts as we try to optimize their flight duration and work schedule in order to reduce total costs for getting a job done?

In order to define an appropriate mix of manned and unmanned operations, NASA will need to "qualify man for space flight" in the broadest sense. That is, NASA should pursue a biomedical program which explores the optimization of man's role in space, the limitations on his effectiveness and means to circumvent those limitations, in short, a program to determine the best use of man as a space subsystem in interaction with automated subsystems. An effective program directed to this objective exceeds the present capabilities of NASA and involves resources not yet developed in the biomedical community. In this report, we will consider the implications of such a program and will offer a number of recommendations intended to accomplish this objective.

We have not attempted to examine in detail man's role in connection with possible military objectives in space, although a broad biomedical foundation for manned space flight would be supportive of both DOD and NASA. To the extent that DOD programs can provide information, space hardware, and facilities that may be of use in the broader context of the civilian program, NASA should take full advantage of these opportunities. Responsibility for exploration of general benefits from and limitations to manned space flight should, we think, remain with NASA.

This report does not concern itself with detailed review of NASA programs in space biology or exobiology, but does emphasize points of contact between these areas and problems of space medicine oriented to the qualification of man for space. Fundamental biology has a proper and important role in space sciences, a self-evident proposition for exobiology. The provision of a sound biomedical foundation for manned space flight, however, is clearly a separate and major goal for NASA planning. If pursued properly, the biomedical program will stimulate additional interest in areas of fundamental biology. It is, however, neither necessary nor desirable to apply to NASA's programs in basic bioscience a requirement for direct relevance to applied biomedicine.

II. PREVIOUS REPORTS ON SPACE BIOMEDICINE

Concern over biomedical foundations of manned space flight is not new. As early as January 1960, the Bioscience Advisory Panel to NASA recommended that NASA assume the responsibility for leadership, coordination, and operation of a national bioastronautics program in which career opportunities would be created for life scientists "motivated toward space research and skilled in its special problems and techniques." An attempt was made to build up such a capability within NASA but the pressure of operations in support of Project Mercury and Gemini inhibited this growth. In November 1961, the infant Life Sciences Division was swallowed by other organizational units within the agency.

In 1962 and again in 1963, PSAC panels observed a continuing lack of biological and medical research experience in NASA as a result of concentration upon the operational and engineering aspects of manned space flight. Perhaps more significantly, a lack of "technical understanding and sympathetic support of biomedical recommendations at the highest, i.e., decision-making, levels of the organization" was singled out as a contributing factor.

In 1967, in the PSAC Post-Apollo Report, it was established that this need had not yet been effectively met and a number of recommendations were offered to upgrade the NASA program.

For the most part, NASA has not chosen to implement recommendations in these reports which might have led to creation of a strong biomedical research capability with adequate resources and extensive, close ties to supporting universities and research laboratories. Pressures for early and reasonably certain success led to placing primary emphasis initially on validation of the capability to construct, orbit, and recover manned spacecraft, with long-range, scientific goals in the biomedical field set aside as potentially interfering with flight objectives. Scientific requirements were thus deemphasized at the very time when development of basic scientific knowledge and a cadre of scientific talent should have been begun. In short, no programmatic stimulus arose for NASA to improve their biomedical program in response to these external recommendations, since early manned programs were designed to avoid biomedical obstacles wherever possible.

Thus in 1969, NASA is faced with the question of qualifying man for more complex tasks in space, for longer duration flights, and of evaluating man as an integral part of the spacecraft man-machine system, without sound biomedical foundations as a basis for addressing these questions. In particular, decisions concerning development directions for the next generation of manned spacecraft systems for use in earth orbit must be made without an adequate basis of understanding.

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III. EVOLUTION OF MAN'S ROLE IN SPACE

A. Evaluation of Man's Performance in Space

The new Administration is faced with making a decision on whether NASA is to continue manned space flight programs after Apollo and to what end. Clearly, decisions regarding programs for man in space will involve consideration of many complex and interrelated political and technical factors. For example, there are many objectives which might benefit from a well-planned and executed manned flight program, including science, space exploration and international cooperation. Although a manned flight program can contribute to all of these objectives, it may not be an indispensable element in any of them and may be an unacceptably expensive route to some. Then why manned flight?

We cannot answer this question with assurance for the long term. We expect that man will play an important role, but we have an imperfect vision of what that role will be. The degree to which we can identify man's role depends critically upon information that does not yet exist. The necessary experiments have yet to be performed, either on the ground or in space, that will "qualify man" in the broad sense, for future space flight.

What do we mean by the phrase--to "qualify" man? This term has been widely used in a restrictive sense, that is, to test man's tolerance for longer duration space missions. Certainly this is part of qualifying man, the determination of man's ability to survive in space over extended periods and continue to perform effectively, maintain satisfactory interpersonal relationships with crew members, not be adversely affected by his return to earth, and maintain his physiological and psychological well-being during this period in space. But in its broader meaning "to qualify man" implies a detailed understanding of the unique capabilities and capacities of the human organism, of the optimal contributions of this organism to the performance of space flight with a wide variety of objectives, and development of a predictive ability for performance or response based upon pre-flight data. One may even regard as part of "qualifying man" new concepts in engineering design needed to take maximum advantage of man's capabilities--both in space and remotely, through the use of broad band communications links. In short, we see the qualification of man as the achievement of a depth of understanding about man and his role in space that will permit his optimal integration into future space programs.

B. Lessons of Early Manned Flight Programs

Where do we stand today in achieving this understanding of man? In the PSAC Post-Apollo Report, an evaluation of biomedical data from manned flight was included as an appendix to support the conclusion that a more scientific basis was required for the qualification of man. Although manned Apollo flights have begun, they are not likely to expand greatly upon the biomedical information gained from the Mercury and Gemini programs. Thus, except for continuation of ground-based studies, only the type of flight data available from the Mercury and Gemini Projects and information reported from the Soviet program is available to aid understanding of man's capability for flights of extreme duration.

The Mercury and Gemini programs were highly successful operations. Because of the restricted duration and objectives of these flights, it was possible for NASA to approach biomedical problems empirically, using an incremental approach to assuring man's survival, i.e., a progressive increase in orbital exposure through a doubling of flight duration while monitoring a number of body functions, but depending upon the astronaut for a qualitative evaluation of his physiological state. In this scheme a high degree of advanced biomedical planning was not thought necessary for success of the immediate project, for in an emergency the astronaut was only a few hours away from reentry, recovery, and earth-based care. For this reason there has been inadequate exploration of many potentially limiting physiological states. For example, assessment of cardiopulmonary functions during sudden severe physical stresses occurring intermittently in space flight remains to be done, yet it is clear that significant cardiovascular deconditioning can result from mere immobility, apart from any accentuation by prolonged periods of weightlessness. No definitive data are available on permissible muscular work in the weightless state and on actual energy expenditure during known levels of effort, despite clear indications that motor efficiency may decline even acutely in weightlessness. Little data has been gathered on changes in circadian and other biological rhythms, although astronauts have encountered significant difficulties in sleeping. Such problems touch on minimal living volumes that can be safely occupied by astronauts for extended periods, and the impact of living volume on effective interpersonal relations. While monitoring and measurement required for purposes of prediction began to be explored in the Gemini flights, this flight program ended while the long term research effort was only in its beginning.

C. The Second Decade of Manned Flight

April 1971 will mark the tenth anniversary of manned space flight. On the threshold of the second decade of manned flight, we are struck by the disparity between our treatment of man and our treatment of the complex systems which comprise the spacecraft, launch vehicle and supporting equipment. Sophistication resulting from our dedicated pursuit of improvement in the engineering of electronic and mechanical systems has not been matched by our capability to utilize man or our understanding of how man is affected by the space environment. But we are entering a period in which

it will become increasingly difficult to justify the use of man without achieving a comparable sophistication.

What criteria are likely to apply to the use of man in the coming decade? They include:

1. Man as an Integral Part of the Complex Man-Machine System.
Impending space missions will benefit from the capability of planning for, and where possible, predicting performance over periods extending to perhaps hundreds of days. We can envision man in the role of ship's captain or crew member capable of contributing to total system reliability in a vehicle necessarily growing unreliable with passing time, rather than in the role of test pilot in systems assumed reliable for the total mission duration. We will see man make judgments on engineering systems and effect repairs in ways not hitherto imperative, and systems will have to be redesigned to make this possible. In short orbital missions, he will no longer play the exclusive role of pilot-astronaut but will necessarily have assignments requiring his intra- and extravehicular mobility and skilled performance in such diverse roles as engineer-technician, biologist, and physical scientist.

2. Performance rather than Survival.
In 1961, when Yuri Gagarin became the first man to orbit the earth, people around the world were profoundly stirred and the value to the USSR of such a flight was widely acknowledged. The demonstration of a capability to achieve such a complex technological feat possessed significant political fall-out. Early U.S. efforts certainly had much the same effect. In establishing the Apollo goal, however, the U.S. chose an objective sufficiently difficult that it would demonstrate our superiority in space technology. But this focus upon Apollo and its predecessor programs resulted in the creation of a space flight medicine capability dedicated to satisfaction of the identified and limited mission requirements of Mercury, Gemini and Apollo. Man is an indispensable part of the Apollo mission, performing certain operations vital to his safe return, including the return of lunar samples and photographs of his experiences on the lunar surface. The principal biomedical criterion for success, however, is safe return.

When faced with this requirement and with deadlines which strained their capabilities to respond, engineers and program managers whose principal background was in missile or aircraft design were led to treat man more as part of the payload of the spacecraft rather than a contributing subsystem, a payload which placed severe demands upon the system for such additional complicating subsystems as life support and environment control. Of course, man contributes in a number of ways; e.g., to actuate switches and levers, to

perform the final control maneuvers for rendezvous and docking, and to control the final pre-touchdown phases of the flight to the moon. But both a lack of design experience and a lack of understanding of the optimal use of man led to minimizing reliance on astronauts to sustain the system reliability. Biomedical studies of man were keyed to assuring his survival in space for a period equivalent to the normal lunar mission duration.

What of the future? What are the objectives toward which the biomedical effort is to be structured?

We are persuaded that the future for man in space rests on his utilization in the performance of useful mental and physical tasks for which he, at present, has no practical substitute. The thrust of the space program for the second decade will emphasize concrete results of value to the Nation more than the development of capabilities for possible future application. Man will need to justify his presence in space functioning as a closely integrated and highly performing part of the mission. This combined system must provide better performance at a given cost than unmanned alternatives. We believe that a comprehensive biomedical program will be required before this objective can be approached.

3. Costs of Failure.

The present cost of manned space flight operations, particularly those operations which involve the present Saturn family of launch vehicles and associated Apollo hardware, is high. A single Saturn V launched Apollo spacecraft is estimated to represent an investment of $300-350 million. (This compares with total Federal expenditures for Heart and Cancer Research in FY 68 of about $350 million or the entire National Science Foundation appropriation for FY 69 of about $400 million.) Following the philosophy of the early manned programs, if a flight crew encountered serious biomedical difficulties the mission would be aborted and the spacecraft returned to earth. Aborting a Saturn V launched mission for such a reason is an extremely expensive technique for solving a biomedical problem. Saving just one such abort would finance an expanded biomedical program for many years. It should also be clear that, in future missions devoted to practical or scientific goals a failure to perform the assigned tasks adequately which results in mission failure is as costly as an abort because of a threat to the medical well-being of the crew. Stated another way, a three man, ten day mission such as Apollo 7 costs over $100 million. If such a mission, in the future, is carried out for the purpose of making a man available in orbit to perform a series of tasks, the cost per man-day for his services is about $3.3 million.

At such cost levels man must add uniquely to the operation, presumably functioning at the highest levels of human capability.

Recently, NASA has given greater emphasis to studies of ways in which significant cost reductions can be achieved in manned flight programs. Such studies have revealed a number of promising alternatives for reducing vehicle costs, but even with order-of-magnitude reductions, manned flight will remain a very costly endeavor, and reducing the probability of mission failure or abort should remain a high priority objective.

Of course, in extended missions out of low earth orbit even the option of mission abort may not be a satisfactory emergency measure in the event of serious medical problems. A high degree of understanding of man will be required, perhaps including specific measures for averting or mitigating adverse affects through better crew selection, environmental control or in-flight medical procedures.

4. Future Missions.

In the 1967 President's Science Advisory Committee Post-Apollo Report, exploration by man of the nearby planets was identified as the most challenging ultimate objective for space exploration.

The role that man might play on such a mission, however, is not clear. If we had to design such a mission today, undoubtedly man would function much as he does in Apollo. We believe that man should not be limited to such a role, which provides an additional reason why a manned planetary mission is not desirable as a program commitment at this time. In any case our knowledge of the physical nature of the planets is likely to remain inadequate to permit serious consideration of such a mission for several years.

But what of other missions which may be considered for approval before manned planetary exploration, and what is man's role?

One major class of missions--the performance of scientific experiments in space--can be expected to develop eventually in a form that will require man to perform demanding tasks vital to mission success. The PSAC Post-Apollo Report discussed a number of such possibilities, including the eventual construction of large complex telescopes in space capable of observations in many regions of the electromagnetic spectrum. Because of the great cost of such instruments, man may assist in the assembly, alignment, repair, replacement and modification of such instruments, if he can do so effectively. We are less convinced that man will play a continuing role in the performance of engineering and applications experiments in space.

We are familiar with the claim that manned systems provide a cost effective way to fly a wide variety of space experiments on a "first flight or non-operational basis." We believe that objective studies of this question should be conducted to isolate fact from folklore in this area. Such studies should take explicit account of the developing capabilities of remotely controlled manipulators, devices which can function to transfer man's anthropomorphic capabilities to a remote and hostile (to man) environment while controlled from a more benign or convenient location. Using such devices, decisions can be performed by many men in a normal environment while controlled from a more benign or convenient location. Using such devices, decisions can be performed by many men in a normal environment using computational aids as required. As the reliability and utility of devices that will give man this remote action capability are improved, they may substitute for many uses of man in earth orbit. We do not wish to prejudge this issue; considerable additional development and study of such devices will be required. But this development should not be inhibited because of arbitrary or restrictive views concerning their ultimate use.

IV. GOALS AND BENEFITS OF A STRENGTHENED BIOMEDICAL PROGRAM

A. Application to Flight Programs

An effective NASA biomedical program eventually would have significant impact upon the possible range of manned missions available for decision, the mission operations which support these prospective commitments, the design and operation of the spacecraft and launch vehicle and the scope of supporting unmanned programs. It could provide a quantitative basis for the manned-unmanned tradeoff in overall program planning and thus in subtle and complex ways, upon the major substance of the future NASA program.

Detailed goals for the applied biomedical program are given in the Recommendations.

In parallel with these goals, directly related to clinical evaluation of man, it would be anticipated that supporting data would be derived from subhuman species, including primates exposed to comparable environments and appropriately instrumented for observations not feasible in man.

As we look into the more distant future, we anticipate that the qualification of man will lead to a new generation of spacecraft in which maintainability is stressed, utilizing man as a reprogrammable, decision-making, integral part of the system performing new missions, the nature of which we cannot clearly see.

B. Broader Benefits from Space Biomedicine

Development of the required skills and knowledge to carry out this qualification program on man will stimulate activity that can be of great benefit on earth.

A biomedical program structured to the needs of NASA in carrying out its assigned role in space offers additional opportunities for fundamental research in biology and biomedicine. The 1960 report of the National Aeronautics and Space Administration Bioscience Advisory Committee gives an excellent summary of the many scientific problems challenging space bioscientists. The report emphasizes opportunities for study of problems in both basic and applied biology, and summarizes the need for more knowledge about kinetic stresses, weightlessness, radiation, closed ecological systems, change in environmental time cycles, and environmental toxicity and contamination.

The opportunity to study man intensively in a highly restricted and instrumented environment while under a wide range of stresses will become possible. Observations of this type with or without the zero gravity state have not been made and would be extremely difficult to duplicate under other circumstances. Such observations would provide fundamental information regarding a healthy man's reaction to his environment. Psychologic stress, immobility and the like could be studied under the most completely controlled environmental circumstances, providing a new stimulus and opportunity to study man's physiologic and psychologic reactions.

In all of terrestrial biology the force of gravity is a subtle and ever present factor. In research such as on the growth of seedlings, the function of the inner ear, and the control of blood pressure it is a recognized but almost non-eradicable factor. The opportunity to use the space environment advances such studies by a giant step. Now the possibility of dissecting away gravity as a fundamental biologic stimulus is present. It is conceivable, for example, that studies on the blood pressure controlling mechanism may be the key to unlock a more complete understanding of basic physiologic mechanisms on a broad basis, rather than being useful solely as a test of an astronaut's reactions to space flight.

Current biosatellite programs have been developed specifically to consider these problems in an orderly progression from simple living forms to subhuman primates. Such specialized experiments have confirmed the need for in-house administrative review and development independent of more applied aspects of biomedical studies in man.

Despite the enormous importance of better understanding of the relationship of a healthy man to the stresses of his environment, the health sciences and related fields have not produced the interdisciplinary teams necessary to meet urgent medical and sociological problems of this type. These talents could be stimulated by the particularly demanding requirements of NASA, drawing on the special talents of the aerospace field. It is therefore of paramount importance that ground-based studies in space biomedicine be regarded from the twin viewpoints of meeting applied needs and also in contributing new and needed technologies in response to critical environmental health problems not likely to be met in the current frame of traditional biomedical research.

In addition, the concepts and techniques basic to space medicine seem to lend themselves particularly to a new and evolving concept--the practice of medicine-at-a-distance or "telemedicine." In NASA this requirement arises for two reasons: (1) high cost of aborting an earth orbital mission prematurely because of doubts about the health of an astronaut, and (2) the impossibility of rapidly returning an astronaut from deep space should he require medical attention. Not only could the physician take a history

at a distance, but perhaps do a type of physical examination. Exciting new developments in this area appear possible.

If we examine the philosophies inherent in design, development and execution of biological and medical experiments in space, many points of interrelationship with pressing problems of terrestrial biology and medicine are apparent:

1) By the comprehensive and expensive character of these space experiments, it is imperative that they attain very high levels of reliability, much beyond usual levels in biomedical laboratories. Attainment of this capability, or at least a wider recognition of the need for substantial upgrading of the quantity and quality of current bioinstrumentation, would offer enormous and widespread benefits in patient care.

2) The nature of biomedical experiments in space, involving limited numbers of subjects and high vehicle costs, demands maximum yield of data from individual subjects, with multiple sensors in all major physiological systems. In many instances, such instrumentation does not now exist, and is particularly weak in meeting monitoring requirements on a non-interference basis. Major developments in multichannel physiological data acquisition would have immediate and urgent application in monitoring man on earth, as well as in such areas as intensive patient care. Moreover, these developments lie properly within the field of aerospace biology and medicine, and are necessary to the special goals of NASA.

3) It is likely that important physiological effects attributable to the space environment will occur as subtle trends over long time periods. For this reason, physiological measurements in space must be sufficiently sensitive and accurate for evaluation of these long term changes. Such measurements have special relevance to public health problems on earth, including such areas as air and water pollution, and food adulteration. These measurements have scarcely begun in the public health domain, due largely to lack of needed technological capabilities in the health sciences. A nucleus of these biomedical engineering capabilities already exists in the aerospace field.

4) Success in biomedical research of the foregoing type, both in space and in terrestrial baseline development, demands new ways of data handling and analysis. There are problems in biomedical data analysis relating to large volumes and high data rates. In turn, these are associated with urgent requirements in pattern recognition that challenge current states of the computational arts. Solution to these problems is a pressing requirement in space biological and medical research, because of its unique scope. The problems have direct and important counterparts in status assessment of individuals on earth.

5) Since interruption of integrity of the skin for medical data acquisition is undesirable in the performing astronaut, there is a need for major developments in transducing systems that measure deep body systems when located on the body surface, or at a distance from the subject. Schemes that have been proposed, or developed in prototype, have done little to accomplish this. They are needed urgently for application to both animals and man in space.

6) Similarly, there is a lack of many types of biological and biomedical instrumentation essential for these measurements and able to meet weight, volume and reliability requirements for space flight. Indeed, much biomedical instrumentation for use in space remains completely undeveloped.

7) It is imperative that all facets of biomedical experiments destined for space flight be developed with clear awareness of the importance of schedule milestones and deadlines. Integration of experiment systems and subsystems demand adherence to these criteria. This requirement is entirely new to most biomedical scientists, accustomed only to small development steps in an experiment sequence. Cohesiveness of these flight experiments is critically dependent on adherence to principles of systems engineering, particularly in the perfecting of varied and usually numerous experiment - spacecraft interfaces. It can be argued that this experience in interdisciplinary, mission-oriented research should be a valuable professional experience for the biologist and clinician.

These examples indicate that a broadly based and sophisticated space biomedical program would have much more to offer than just support to space medicine and biomedical problems in space. A wide range of dividends ranging from fundamentals of cell growth and observation of complex psycho-physiologic reactions of man to the development of a stronger bioengineering program for the Nation can be anticipated. Even more important the successful development of techniques and research capabilities appropriate for solving space biomedical problems will transform the practice of biomedical research itself, with great consequences to the future of medical science. Indeed the test of the success of the recommended program is the extent to which the stimulation of NASA's demanding requirements brings about constructive changes in the science of biomedical research practice and capability. These broader implications support the need for a strong NASA biomedical program.

V. HUMAN RESOURCE REQUIREMENTS

A. Within the Scientific Community.

If NASA is to upgrade its biomedical effort, a vital element in this process will be the available human resources of talented, dedicated, knowledgable biomedical research and management personnel. Other government agencies or segments of the economy also have unrealized needs for sophisticated biomedical support, but for the most part they have not had the incentive or the large resources to develop new methods of measurement, remote and automated sensing devices, and miniaturization of instruments that meet constraints of weight, space, time, electric power and recycling of materials which must be met by biomedical scientists working in space. Space biomedical research requires a different mix of physicians, life scientists, engineers, physicists and mathematicians than is commonly present in single university departments or supported in specialized research institutes by the NIH or NSF. The future needs of the NASA will be met by new and specific developments in space biology and medicine, with abundant opportunity for collaboration of biomedical and engineering specialists. The requirement for such skills cannot be adequately met at present and active effort is required to stimulate development of the numbers of broadly trained investigators required. Few biomedical scientists are directly concerned with the methodology needed for working effectively and imaginatively in the space medium. The transition to biological experimentation in space is intricate, extremely expensive and time consuming. Like many other ground-based investigators, the biologist traditionally has worked in an environment populated mostly by people like himself, used to a small operation in which overhead is not high and in which the penalty for failure of any one experiment is correspondingly low. He avoids confrontation with constraints of space, weight, power requirements, isolation and the need to reutilize materials. He has rarely considered the complexities of completely automated experiments. Equipment size is usually not a consideration if it is fiscally feasible and gives him information. Because animal tissue or cells are easily available and control of multiple variables is difficult, bioscientists commonly make only a limited number of types of observations during any one experiment. The problem is resolved part by part in multiple series of experiments, and gradually the attempt is made over months or years to synthesize some portion of the whole from the separate units of information. On this basis it is not surprising that bioscientists experience difficulty in designing highly significant experiments for space flight. On the other hand, engineers have traditionally lived in a world divorced from biological considerations, have lacked appreciation of the complexity of biological systems and are unaware of the many perturbations that can be produced by any form of manipulation. They tend to oversimplify biological systems in models that have little or no relevance to living systems, are discouraged because the systems are too

complex to be characterized by their usual frames of reference and are dismayed by biomedical scientists who do not give them finished research protocols from which engineering hardware designs will logically follow. Moreover, most aerospace engineers have had little or no experience in collaboration at a bioengineering interface.

Finally, the general medical community is not experienced in dealing with minor changes in high-level performance of small numbers of very healthy individuals. The requirement for prediction of conditions of health, while of great value if successfully attained, is beyond present medical capability.

The situation is not hopeless, however, and with the proper motivation and continuity of effort, the needed talents in both the biomedical and engineering communities can be developed. The lead times for generating significant progress in developing interested and space research-oriented investigators are going to be long due to the unique nature of the space biomedical requirements.

B. Within NASA.

NASA has had the benefit of a series of ad hoc committee reports which have stressed the need to develop further competence in the life sciences within the Agency. NASA has constructed a biomedical organization which concentrated largely upon the support of flight programs, Mercury, Gemini and Apollo, with little emphasis upon the longer-range education and research aspects of manned space flight programs. The "critical mass" of talented, research-oriented biomedical personnel necessary for the creation of a vigorous fundamental program was never assembled and the press of operational support problems generated by the flight programs has consumed the time of the people capable of sustaining such an effort. When faced with the challenge of designing biomedical programs for the post-Apollo period, the Agency lacked the biomedical personnel to deal effectively with these problems.

Only a small fraction of those trained personnel who are needed to carry out the program that we envision are actually required within NASA to achieve increases in biomedical competence. NASA can be expected to derive most of its research support from outside the NASA Centers, but for this support to be effectively managed adequate incentives must be made available to attract and hold the knowledgable and effective biomedical supervisors required for management of a long-range investigative program.

C. Biomedical Scientist Astronauts.

The biomedical scientist astronaut must become an effective member of ground-based research teams, if he is to fulfill a later role as a flight investigator. His task will lie in space biology and fundamental physiology to the same degree as in clinical

medical research. The need for scientist astronauts in ground-based studies in academic institutions as well as in NASA Centers is already in excess of those selected in the field of the biomedical sciences, and emphasizes the importance of their carefully planned inclusion in terrestrial studies, as well as in actual flight missions. Their participation in terrestrial studies throughout the years of astronaut training would serve to maintain professional competence and competitiveness in their respective fields of specialization. The continued involvement of scientist astronauts in productive research in their areas of interest will have a dual benefit. First, it will divorce the astronaut from a strong dependence upon the frequency of space flights, since prolonged pauses between flights would not detract from the useful employment of the astronaut's skills. Second, it will provide a useful and productive bridge between the research frontier and the application of the astronaut's expertise to operational space flight problems.

VI. RECOMMENDATIONS

In the preceeding sections, we have outlined the general scope of the problem facing NASA and the contributions that an enhanced biomedical program can be expected to make toward the solution of that problem. As we pointed out, much of our comment closely parallels advice given to NASA by a series of earlier groups that have studied the question of biomedical support for the Agency. We have also suggested a number of reasons why NASA has not chosen to accept all of the advice it has received, particularly concerning the development of a broadly-based biomedical research capability. We believe, however, that the situation which NASA faces today is significantly different than that faced at the time of these earlier reports when Apollo was the main objective. Now, the maintenance of a viable NASA manned-flight program may very well depend upon a strong and basically redirected biomedical effort. In any case we believe that great benefit to man on earth would derive from the development of the research capabilities required for space biomedicine.

In the following recommendations we have not attempted to relate a specific set of objectives to a set of missions, nor have we criticized specific planned missions such as the S-IVB orbital workshop or the ATM, which were discussed in the February 67 PSAC Post-Apollo Report, primarily because these are short term engineering oriented flight programs that cannot benefit appreciably from biomedical research not yet underway. Rather, we have concentrated upon the implications of decisions about the character and scope of manned missions upon the biomedical programs of the NASA and conversely, the implications of existing biomedical programs (if allowed to continue) and of strengthened biomedical programs, upon the character of the associated manned flights.

Under the present budgetary constraints, post-Apollo manned space flight programs are being reduced in scope and slipped in time and manned planetary exploration is no longer an immediate concern. NASA now has the time to design and implement programs for studies of manned flight, for the development of ground-based programs and institutions in the scientific community which support these studies, and for the strengthening of its overall biomedical capabilities.

By the nature of their separate but related goals, a healthy development of NASA in-house capability in both space biology and clinical medicine should sustain existing aspects of separate program development. Programs in clinical medicine cannot replace needed research in general biology or fundamental physiology, nor should needs in the latter be considered secondary to the former. It is imperative, however, that there be closer coupling between NASA divisions currently entrusted with the separate development of these missions.

A. Biomedical Research.

It is necessary for NASA and DOD to enter into environmental biological studies with more specific and more persistent purpose than until now has been required for support of manned space flight. It has been customary for investigators to explore the stresses of a new environment by cautious empirical approach and withdrawal, solving the immediate problems which become apparent, and procrastinating over the risk of injury from chronic or delayed effects of the new environment. Information has been only slowly accumulated about the biologic effects of silicon, beryllium, X-rays, and tobacco smoke. A purposeful and rapid development of the science of environmental medicine is now indicated, and special attention is required for the sustained severe stresses of space flight. On a cost basis the space agency can justify a program, expensive in both dollars and scientific manpower, for the successful prediction of the effects of environment on man confined in a small space over a long period of time. Prevention of failure of one major space venture will justify the entire cost of the program.

We recommend greater emphasis upon innovative research which provides the foundation for biomedical programs both in manned space flight and in other fields of bioscience related to space. The key aspects requiring such fundamental study have been identified and include among them such areas as weightlessness, the respiratory and tissue gas exchange, radiation effects, toxic consequences of closed environments, the dermatological interface, and pharmacological peculiarities of space flight. These and other research opportunities require long lead time, the interest of investigators and, in some instances, highly specialized facilities.

B. Applied Goals.

In addition to basic studies, goals of the overall biomedical program should include means for improving the degree of success of manned missions. We recommend that the biomedical research program be designed to contribute to such applied objectives as:

(a) Development of criteria for crew selection and training.

(b) Prediction of the effects of long flights from data collected in preceding terrestrial simulations, or in previous flights.

(c) Prediction of probabilities of failure in major biological systems, through continuous monitoring and measurements of small changes.

(d) Development of techniques for evaluating the level of astronaut performance and alleviating degradations in performance associated with environmental stresses or biomedical derangements.

(e) Understanding of the ability of man to perform useful work in or adjacent to orbiting vehicles.

(f) Development of techniques for circumventing limitations, through development of "telefactors" for man-controlled remote operations.

(g) Understanding of the man-machine relationship that will enable further progress in defining biomedical research requirements and engineering to maximize the value of man's participation in the system.

(h) Understanding of optimum crew size and mission duration for astronaut-assisted programs, from which sound principles for design of manned space systems can be derived.

It is expected that the proper study of man will lead to a new generation of spacecraft in which maintainability is stressed, utilizing man as a decision-making, integral part of the system performing new missions, the nature of which cannot be seen at the present time.

C. Research Facilities.

While a broad range of composite biomedical research facilities and capabilities has evolved within the various elements of the DOD, AEC and NIH, the degree to which these Federal resources have been utilized in detailed support of the space program has been limited, as has development or support of biomedical capabilities within universities. It is toward evolution and use of such assets that the long-term biomedical program plan must be directed, since it is clearly impractical to consider establishment within NASA of the many and varied biomedical laboratories, or the extensive and versatile investigative staffs required.

Therefore, we recommend that NASA plan its overall biomedical program with regard for the resources, personnel and experience available within other areas of government, and particularly within the DOD. We recommend as well the establishment of mechanisms for development and long-term support of the needed multidisciplinary environmental medical laboratories within universities.

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D. International Cooperation in Space Biomedicine.

The Panel strongly favors the development of new avenues for international cooperation in the exploration of space for peaceful purposes. Great emphasis has been given to space biomedicine in the USSR and special expertise exists in several other nations. We recommend that NASA continue to seek opportunities for cooperation in this area of research, which promises significant benefits to mankind generally.

E. Relation to the Academic Community.

Operational demands of manned space flight projects and the resulting difficulty in developing long-range programs of biomedical research have handicapped the evolution of close and detailed working relationships between NASA and many academic investigators well qualified to participate in the space program. This human resource is a vital element in the formulation, and conduct of the biomedical research program that we have described.

We recommend that sustained effort be exerted by NASA to develop close communication with the biomedical community in general, including the exchange of information through scientific reporting, symposia, summer studies and other devices.

We recommend that an active mechanism be utilized to broaden the participation of biomedical scientists in planned and approved manned space flight programs, and in the long term biomedical studies basic to these programs.

F. Advisory Functions in Biomedical Sciences.

NASA periodically invites advisory groups in biology and biomedicine to advise it on the experiments that should be conducted on a particular space flight or upon the general state of its biomedical program. In reports of such groups, which have spanned the lifetime of the agency, scientists have offered advice concerning program needs, but have been rather unsuccessful in influencing the basic character and policy of the NASA biomedical program. While a short term ad hoc advisory group, by its nature cannot follow-up on the response to its recommendations, as repeated recommendations concerning long-range scientific goals were not implemented, general disenchantment of originally interested biomedical scientists resulted.

We recommend therefore that NASA establish mechanisms for enlisting the continuing support and advice of university and industrial biomedical scientists.

G. Biomedical Scientist Astronauts.

The manned space flight program will require extensive biomedical testing and experimentation during space flight as a supplement to a broad ground-based program of studies and experiments. In order to carry out such experimentation effectively, highly motivated biomedical astronauts will be required. There will be a similar requirement for specialists in space biology and fundamental physiology.

We recommend that NASA establish a program that provides adequate incentives and professional opportunities for groups of biologically and medically trained astronauts, responsive not only to operational problems related to missions but also responsive to the needs of both biological and medical research programs. To this end serious consideration should be given to organizational arrangements that would permit biomedical astronauts to be affiliated with either the biological or medical research components of NASA or qualified institutions, and be assigned to the flight-crew organization at Houston only when designated to participate in specific missions.

H. Organization.

The Panel considered existing mechanisms within NASA for carrying out biomedical programs responsive to the objectives we have outlined. Many of the problems facing the Agency are of such a nature that the present fragmented structure for the life sciences will be unable to bring about the necessary programs either within NASA or in supporting biomedical science community. It seems clear to us, therefore, that a major shift in emphasis toward the biomedical sciences must occur within the manned space flight program of the Agency.

We are not prepared to advocate a specific organization for the accomplishment of these goals. As an external advisory body, we are not exposed to all of the constraints under which NASA's organizational decisions must be made, but nevertheless we feel compelled to identify the characteristics of such an organization and bring into focus the objectives or the criteria by which the performance of this organization may be evaluated.

A number of carefully prepared reports have been made available at various times and at various levels in NASA with recommendations similar to or identical with those contained in this report. These reports were accepted but did not succeed in stimulating a sufficiently positive response to cause the Agency to take effective remedial action. We believe that a key component of this problem is the great difficulty in communication between uncommitted advisers and those who carry responsibility not only for the design and development of complex systems, but also and at the same time, for decisions concerning the mission readiness of these systems under externally imposed and relatively inflexible time schedules.

We have also observed a similar communication problem between the life sciences and the engineering and management operations within NASA itself. This difficulty can be attributed largely to organizational arrangements which require managers and engineers in central positions of authority in NASA to make decisions of a multidisciplinary character without an adequate voice in these councils from the biomedical area.

Thus, we have identified the following set of what we believe are crucial criteria pertaining to the organization of NASA--crucial in the sense that their understanding and acceptance by NASA's top management necessarily underlies the usefulness of our other recommendations in affecting the future of the manned space flight program:

1. Independent Authority.

NASA must relate its biomedical program to the hardware, planning, design, and operations groups so that major investments of resources are not made independent of the capabilities of the manned components. These capabilities should be defined by biomedical specialists not themselves part of, nor responsible to organizational elements charged with hardware development or operations. And, in the same spirit, responsibility for the content of the biomedical research and testing programs from which is expected to flow the knowledge required for the planning of extended or complex future manned missions must be in the hands of life science specialists having this kind of organizational independence.

It is of great importance that the planning of biomedical experiments must be the perogative of life scientists before constraints are imposed solely from engineering considerations. Special significance will attach to this perogative in impending development of vehicles for prolonged manned occupancy, and in extended exposure of subhuman species to the space environment.

It has been the common experience of life scientists that engineering contingencies arising in the evolution of spacecraft systems are all too often made the pretext for progressive restriction in scope and content of biomedical experiments. Inability of engineers and life scientists to communicate effectively at engineering interfaces has greatly aggravated these problems.

The independent authority proposed here for the biological and medical operations thus carried an implicit requirement for high levels of biomedical engineering competence necessary to insure effective communication with spacecraft engineers.

2. Unity of Life Sciences.

In addition to providing the life sciences with independent authority, the life sciences must not be artificially fragmented within the agency. At the same time, space biology and fundamental physiology must enjoy requisite levels of independent development that would insure that their investigation is not hampered by pragmatic considerations of applied problems in clinical medicine.

Biology is a continuum which stretches from the viruses to man. With the present organizational pattern of NASA, manned operations and research on man as the subject is carried out predominantly in one set of offices, while animal experimentation is primarily in another office, a situation that has led to a dichotomy of thinking about animal vs manned participation in experimental programs. Basic research in biology, including exobiology, is supported by the Office of Space Science and Applications. These programs have attracted very little collaborative interest in other program offices.

The space bioscience programs and basic biomedical research should be kept in close communication. When and if the biomedical research organization has demonstrated its scientific competence and perspective the bioscience and biomedical research programs might advantageously be combined in a single organization.

We recommend that NASA consider new organizational forms suitable to the need for enhanced space biomedical research, both basic and applied, and separated from the operational organization devoted to the conduct of space missions. The new biomedical research groups would be independent of the flight medical services provided in connection with flight operations, although the latter might advantageously be staffed with medical personnel recruited by and on assignment from the NASA biomedical research organization.

I. Cost and Time Scale for Initiating Action on These Recommendations.

The cost of developing the capability and research program recommended in this report is difficult to specify, and in any case the rate of progress will depend on the response of the scientific community and the availability of talent and institutions prepared to share a long-term mutual commitment with NASA. At the present time the resources in NASA around which the new program can be built are very thin. For example, in FY '68 with a total life science budget of $80 million, $30 million was spent for bioscience spacecraft and only $16 million devoted to matters directly related to the manned space program. This was only 0.6% of the total expenditures of the Office of Manned Space Flight. Our recommendation is that within the manned space flight program--and more particularly within the Apollo Applications Program a greater fraction of resources should be devoted to the biomedical basis for maximizing the benefits of the program. We are not prepared to advocate a specific level of effort since the essence of our recommendations requires primarily a modified outlook toward biomedicine rather than the accomplishment of clearly identifiable tasks. We emphasize the thrust of our recommendations depends vitally upon people--rather than funds--and that progress is possible even at the present funding levels. Thus, this recommendation is not intended to support an accelerated AAP but is directed at achieving a balanced effort within the program.

Prompt action on these recommendations is required because the lead time for building up the capability and interest in the scientific community and the difficulty of the problems insure that even prompt action will not result in substantial impact on success and value of manned flight operations until the mid 70's. Thus for some years to come decisions on the characteristics of manned spacecraft for earth orbital operations, assessment of optimal modes for using man, specification of possible space stations will continue to depend on the present empirical approach. Admittedly the problem we seek to ameliorate is a long range problem, and the scientific development we urge will pay off most heavily over the long term; to this extent prompt action on our recommendations is not "urgent." But no one can doubt the urgency of conducting any program involving hundreds of millions of dollars in the best way. With the success of Apollo, quick action is certainly imperative.

APPENDIX A

PRESIDENT'S SCIENCE ADVISORY COMMITTEE

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	Dr. Richard L. Garwin IBM Watson Research Laboratory
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	Dr. F. H. Westheimer Harvard University
	Dr. Harland G. Wood Case Western Reserve University
<u>Executive Officer</u>	Mr. David Beckler Office of Science and Technology

APPENDIX B

SPACE SCIENCE AND TECHNOLOGY PANEL

In October 1967, the Space Science and Technology Panel convened a working group on Space Medicine, chaired by Dr. Eugene Stead, to study biomedical aspects of the space program with particular emphasis upon manned space flight.

The Biomedical Working Group met with NASA officials responsible for biomedical aspects of the space program and visited several NASA Centers; Ames Research Center, the Manned Spacecraft Center (Houston), NASA Headquarters and the Brooks Air Force Base aeromedical research facility. In addition the group familiarized itself with analogous activities such as the Navy's Sealab Project and discussed problems of confinement and isolation with personnel from the National Institutes of Health, the Navy and the Air Force. The basic conclusions and recommendations in the report were reviewed in draft form with NASA officials in March 1969.

Although detailed work was largely carried out by the Biomedical Working Group, the Space Science and Technology Panel participated fully in the discussion of this problem and in the preparation of the report. Thus this report is the joint effort of technical people whose backgrounds include medicine, physiology, biology, physics, astronomy and engineering.

Panel and Biomedical Working Group members are indicated on the following list:

+Dr. Lewis M. Branscomb, Chairman
National Bureau of Standards

+Dr. William R. Adey
University of California at Los Angeles

+Dr. Ivan L. Bennett, Jr.
New York University Medical Center

Dr. Hendrick W. Bode
Harvard University

+Dr. Melvin Calvin
University of California

Dr. J. W. Chamberlain
Kitt Peak National Observatory

Dr. Allen F. Donovan
Aerospace Corporation

Dr. Howard W. Emmons
Harvard University

Dr. Thomas Gold
Cornell University

+Dr. Christian Lambertsen
University of Pennsylvania

Dr. Franklin A. Long
Cornell University

+Dr. Colin M. MacLeod
The Commonwealth Fund

Dr. Gordon J. F. MacDonald
University of California

Dr. Bruce Murray
California Institute of Technology

Dr. Irwin Shapiro
Massachusetts Institute of Technology

+Dr. Eugene A. Stead, Jr. Chairman, Biomedical Working Group
Duke University

+Dr. James Warren
Ohio State University

+Member, Biomedical Working Group

Mr. KARTH. Now for today's witnesses. Since your name is at the head of the list, Dr. Adey, would you proceed, sir. Do you have a prepared statement?

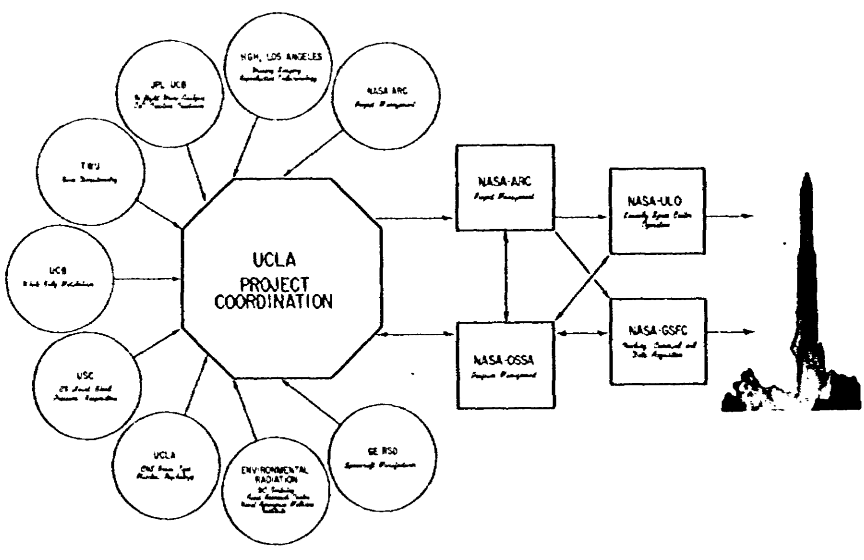
Dr. ADEY. Yes, sir.

STATEMENT OF DR. W. ROSS ADEY, PROFESSOR OF ANATOMY AND PHYSIOLOGY, DIRECTOR, SPACE BIOLOGY LABORATORY, UNIVERSITY OF CALIFORNIA AT LOS ANGELES

Dr. ADEY. Mr. Chairman, members of the subcommittee, on behalf of the experimenters, I welcome this opportunity to appear before you today and to present data relating to the Biosatellite III flight and also, if I may, to draw attention to certain prospects and plans which we feel may be helpful for the committee in evaluating the national need.

In the Biosatellite III flight, our Space Biology Laboratory at UCLA has been responsible since 1964 for coordination of the scientific aspects of the Biosatellite III primate flight, in addition to preparation of the central nervous and behavioral aspects of the experiment.

If I can have the first slide, please?



BIOSATELLITE III, SEPTEMBER 1969 UCLA SPACE BIOLOGY LABORATORY

Dr. ADEY. From its initial formulation around investigations of nervous and cardiovascular functions in a highly instrumented primate, the experiment came to include comprehensive pre- and postflight metabolic studies and in-flight urine analysis, and investigation of bone density and reproductive physiology.

Environmental measurements were equally detailed, and included new methods of radiation sensing, as well as detailed observations on the space capsule atmosphere.

This slide shows the separate segments of the experiment. The first circle at the top right inicates the participation by the Ames Research Center; the other circles show in succession the work of the Harbor General Hospital in Los Angeles in preparing the animal for the urine

collection and in studies of reproductive physiology; the Jet Propulsion Laboratory, and the University of California at Berkeley in inflight urine analysis; the Texas Woman's University, bone density by X-ray methods; the University of California at Berkeley in whole body metabolism; the University of Southern California, through Dr. Meehan and his group, were much involved in cardiovascular studies; next, UCLA, brain and behavior studies; and then environmental radiation estimated by the Lawrence Laboratory at Berkeley, and GE was involved not only with the spacecraft construction, but also in many aspects of the environmental control for the animal and in insuring the sterility in urine collection.

If we trace that graph to the right, it indicates the experimenter involvement with the Ames Research Center and OSS at headquarters, and then as we progressed toward flight and beyond, we have ULO at Cape Kennedy and the Goddard Flight Space Center in data tracking and acquisition.

It was thus a very comprehensive experiment, and necessarily the preparation time was long and the details were extremely carefully considred as the experiment progressed.

The experiment was uniquely comprehensive, and the range of measurements in different body systems, and their detailed character, are without parallel in any single previous experiment on earth or in space.

I would like to indicate certain flight guidelines that were necessary in pursuit of this flight.

It appears important to emphasize the character of bioinstrumentation in this animal. Since the flight, much uninformed criticism has been leveled at the experiment on the grounds of excessive instrumentation. Some have suggested that the monkey was half dead at the time of launch, or that the nature and amount of the instrumentation seriously jeopardized chances of survival.

Many of these opinions are attributed to clinicians who, though qualified in the duties of flight surgeons, do not have appropriate backgrounds in modern techniques of experimental physiology to pass judgment on the feasibility of such combined instrumentation and its compatibility with continued well-being of the subject.

Mr. KARTH. Anyone in particular you have in mind, doctor?

Dr. ADEY. The information that I have was gathered from press comments. I have had exchanges with some of the medical people within NASA, and they have privately, but explicitly, said that they felt that this was the case, that the instrumentation was excessive.

Mr. KARTH. In what office of the agency?

Dr. ADEY. In the medical side of the Office of Manned Space Flight.

Mr. MOSHER. You say NASA said the instrumentation was excessive?

Dr. ADEY. Some of the medical members of the staff of the Office of Manned Space Flight felt this was excessive.

Mr. MOSHER. And you challenge that?

Dr. ADEY. I challenge that.

It should be emphasized that each and every step of the implantation of deep sensors in brain and heart have a long and successful history of use in man in the hospital environment. This history began with animal experimentation. The methods were then successfully adapted to clinical investigations in man, and thus shown to be compatible with his reasonable comfort and general well-being.

Our application of these methods to the monkey, therefore, have represented third order development of well-trodden investigative paths.

Nor was the monkey flown in Biosatellite III in an incapacitated condition. His general health was good at the time of the launch, and as will be shown, he remained alert until the eighth flight day. The backup animal selected as the flight alternate, and subjected to identical implantations and preflight surgical procedures, remains in excellent health in our laboratory, and exhibits all aspects of normal social behavior.

It is true that these animals were heavily instrumented. It was for that reason that intensive preparatory efforts were devoted to developing the necessary team skills without which the delicately timed combination of interinstitutional steps might not have succeeded in bringing the five final candidates to flight readiness in such an exemplary fashion.

Could we have the next slide.

Flight primate in the transporter/simulator during countdown

Dr. ADEY. This shows the flight candidate in the final phase before insertion into the capsule. He was a healthy male and, as Dr. Reynolds indicated yesterday, the necessary operative procedures carried out in the 15 days before the launch had been completed at the time this picture was taken, and the animal was in good condition.

Here again, it should be emphasized that those subjects not flown were merely part of a much broader series of baseline animals tested in every aspect of flight simulation, including the full 30 days of isolation with full instrumentation. The final slide shows the monkey in the capsule.

Looking down on the primate in the capsule. The pellet feeder and it's eight slots is clearly visible. The water dispenser is placed even with the primate's mouth.

Dr. Adey. The first of these 30-day tests was successfully completed 12 months before the launch date.

This is the animal in one of these simulated capsules, and I show this picture to emphasize the completeness with which the simulations were carried out. The vehicle that you see there is identical with the flight vehicle, and the question of isolation of the subject was fully considered and the flight animal had been adapted as far as possible to isolation in capsules of this kind.

Next, I would like to turn to the scientific goals of the Biosatellite III. These were briefly discussed yesterday by Dr. Reynolds.

The specific goals of this flight were to study cycles of sleep and wakefulness; states of attention, including levels of alertness accompanying performance of two tasks, one involving perception and recent memory, and the other testing eye and hand coordination; detailed aspects of sleep cycles, including measures of rapid eye movement (REM) sleep associated with dreaming; continuous measurements of pressures in central vascular structures, including measurements within the heart itself; pre- and post-flight studies of whole body metabolism, to reveal changes in fluid distribution in body tissues and blood about which fragmentary evidence is available from manned flights; to estimate urinary excretion of calcium, creatine, and creatinine every 6 hours during the flight; to evaluate changes in bone density attributable to calcium loss, and to study effects of prolonged weightlessness on the reproductive system.

These investigations were predicated on the philosophy that information so gathered should either have baseline and/or predictive value in relation to known or anticipated needs in manned space-

flight or involve areas of fundamental biology in which new knowledge is urgently needed, as a contribution to terrestrial biology and medicine.

Second, this information could not be gathered as effectively from studies in man, by reasons of hazards in instrumentation, or by required continuity of prolonged observations in subjects intentionally guarded from unscheluded perturbations in sleep or work routines.

Mr. KARTH. You mean in the space environment—that is, in actual flight—the hazards of instrumentation are not apparent because this has been done in man previously?

Dr. ADEY. The hazardous aspect in general relates to the launch and reentry phases when the accelerations associated with the booster may conceivably cause damage in this respect.

Mr. KARTH. Might that have caused damage in the monkey?

Dr. ADEY. It did not. We are able to say on the basis of the autopsy on the flight animal that the instrumentation did not cause damage to the brain or heart or in any other aspects.

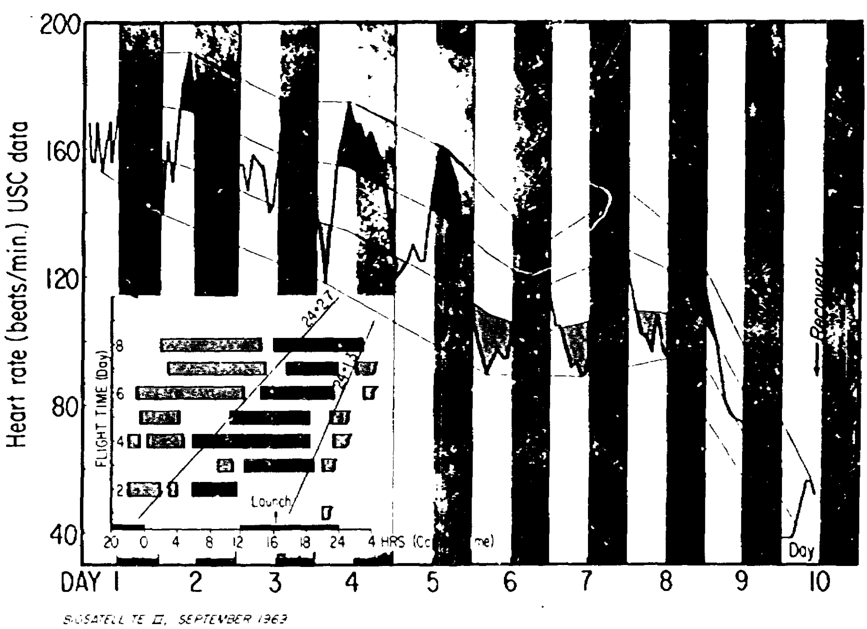
Mr. KARTH. You are unwilling to take that chance with man, however.

Dr. ADEY. That is correct.

Next, I would like to briefly discuss the data from the Biosatellite III, the preliminary analysis. This flight should not be classed as a failure. Preliminary examination of data from the Biosatellite III flight indicate that the monkey remained alert in his waking periods until day eight.

Much new information has been gathered on cycles of sleep and wakefulness in weightlessness.

Could we have the next slide.



The first indications of phase displacement in biorhythm was noted in the heart rate

Dr. ADEY. It is clear that the animal lost his normal circadian or 24-hour rhythm and was no longer synchronized to the capsule day-night cycle. There was a progressive phase displacement of 8 hours in the daily peak of his metabolic and brain wave activities so that by day eight, he slept late into the morning period.

This graph indicates the heart rate on a day-by-day basis and one can see the normal peaks and troughs in the daily heart rate cycle.

In order to estimate whether or not the animal is keeping the daily rhythm, the average heart rate, or what is called the mean, is calculated and that is the centerline running through the graph. It is calculated for each day, and then the variations about that middle line are also calculated; and in this way, we can tell at what time of the day the animal shifts from the day cycle to the night cycle.

In the bottom left of the graph are the days running by No. 1, 2, 3, 4, 5, 6 to 8, and along the horizontal axis of the graph are the hours, 0 to 24.

You notice on the graph that for each day there are horizontal bars. On the left they are black, in the middle they are gray, and then they are black again on the right.

The junction between black and gray is the junction between night and day. The junction between orange and red is the junction between the day and night, and the slope of those lines indicates the period of the animal's daily cycle, and briefly at the junction between day and night we conclude that his cycle was 24 plus 2.7 hours; that is to say, 26 hours long, and at the junction of day and night, it is 24 plus 1.3; that is something over 25 hours.

This amount of data is the minimum on which one could base an opinion that indicated a shifting daily rhythm. We may say that he had a severe phase shift and probably the rhythm became free running, that is to say, it was not constrained by the 12 hours of day and the 12 hours of night that we gave the animal by the lighting regime. He had bright light during the day, and a very dim light during the night.

Mr. KARTH. Doctor, may I ask a question.

Dr. ADEY. Yes, sir.

Mr. KARTH. The graph itself seems to have a descending trend beginning with the first day.

Dr. ADEY. That is correct, yes.

Mr. KARTH. That is, until the sixth day, the end of the sixth day, when the graph ascends, and then descends again on the eighth day.

Can you explain the reason for the descending character of that graph for the first 5 days?

Dr. ADEY. Yes, Mr. Karth. A graph of that kind is very common for monkeys that are put into isolation from man after extended exposure to man, and Dr. Meehan will probably speak to this point specifically, because this is in his area. But it was the common experience in ground tests conducted by Dr. Meehan that the pulse drifts downward.

Mr. KARTH. In other words, you consider that to be normal.

Dr. ADEY. That would be a normal slope.

Mr. KARTH. Beginning with the end of the sixth day, where the graph ascends, which you consider to be abnormal, and then it descends again.

Dr. ADEY. Not directly. I think, if you don't mind, I will refer that question to Dr. Meehan.

Dr. MEEHAN. The heart rate of the animal started out at a rather high value, and then it fell. This is probably an expression of anxiety on the part of the animal which dissipates as he is in his period of isolation and removed from man.

The heart rate would recover or tend to level out after a period of 4 or 5 days, and this is probably what is going on in the rise that you are questioning about.

Mr. KARTH. In your dry-run experimentations, did you find the same thing to be true?

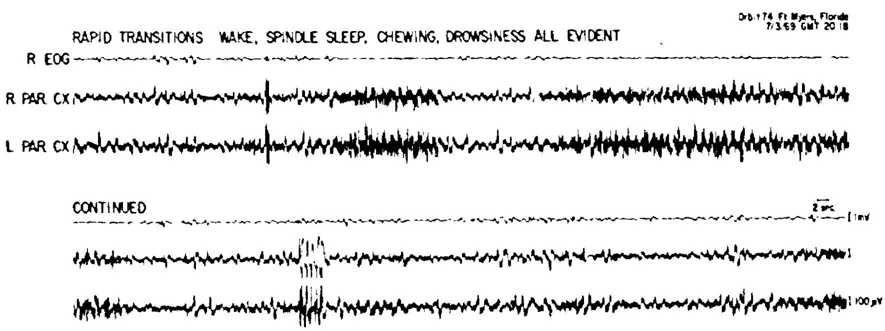
Dr. MEEHAN. Yes, sir. This is of no consequence to the function of the cardiovascular system overall.

Mr. KARTH. Thank you. I didn't understand the graph.

Dr. ADEY. Thank you, sir.

I should point out that no such changes of this kind with this drifting daily rhythm were seen prior to the launch in the flight monkey nor in numerous control animals.

Major disturbances in the circadian rhythms must be taken into account when considering ability to respond at a particular time of day or night to tasks requiring high levels of mental or physical effort.



Dr. ADEY. For the first time in any space flight of man or animals, the occurrence of rapid eye movement (REM) sleep was confirmed. This sleep constitutes about 20 percent of normal sleep on earth and, in man, is associated with dreaming. Further analysis will indicate approximate proportions of REM and other sleep states.

Mr. KARTH. You mean if you don't dream 20 percent of the time, you are in trouble?

Dr. ADEY. Yes, sir, briefly.

Mr. KARTH. All right. It is good to know.

Dr. ADEY. If your time permits, I would be happy to talk to that later, perhaps, or now, if you wish. But, it is true that if one does not have normal amount of sleep, it is followed by psychologically abnormal behavior, often associated with delusions of persecution and hallucinations.

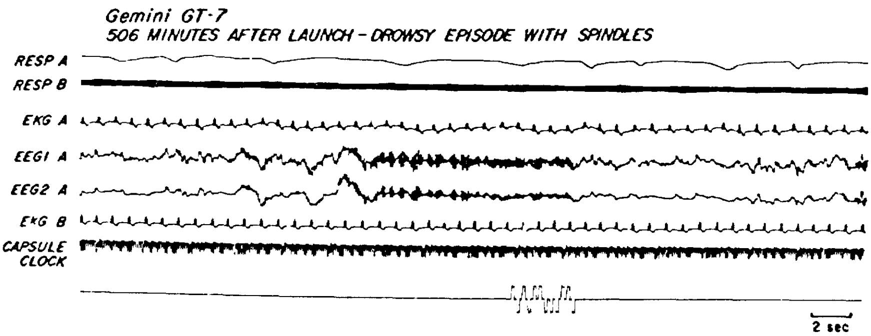
Mr. KARTH. I was wondering if that was the matter with my dog. [Laughter.]

Dr. ADEY. Sleep throughout the flight was characterized by rapid changes in state quite different from baseline studies.

This is an example of the brain wave records from the animal in orbit 74, which would put it on the fourth day of flight. Without going into details of these brain wave records, the point is that they show very rapid transitions.

There are two channels of brain wave records, and one channel of eye movements. The monkey shifted from being awake to what we call splindle sleep, that is, the medium stage of sleep; awake again; then into light sleep; and then awake, with chewing movements; and then back again to a drowsy state at the end of the record. This occurred in a period of approximately 2 minutes.

The day periods were also characterized by sudden shifts to brief episodes of drowsiness or actual sleep followed by sudden waking. These rapid shifts in the awake state also characterized brain wave records from astronaut Borman in the Gemini 7 flight.

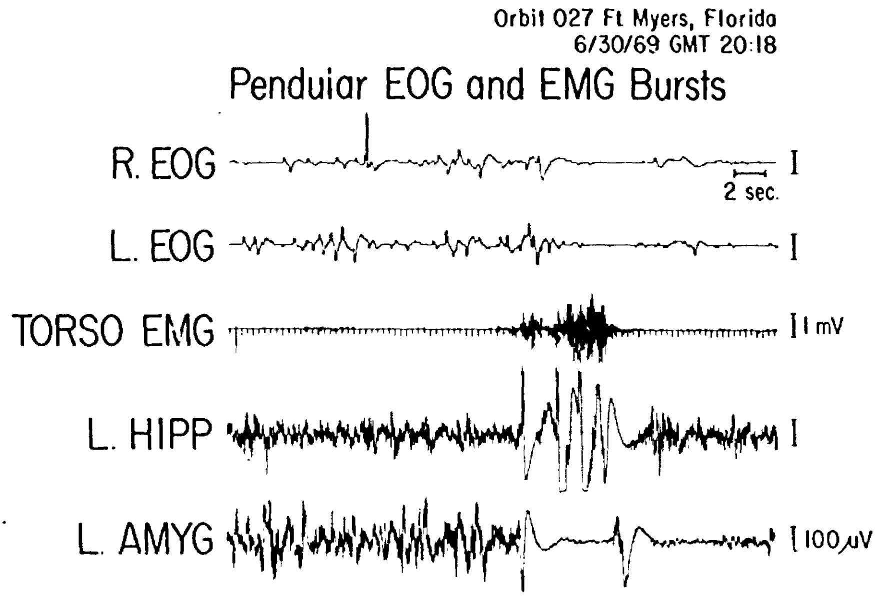


Rapid transitions in wakefulness in Astronaut F. Borman on day 1 of Gemini GT-7 flight. Figure shows 8 data channels: (1) Borman's respiration, (2) Lovell's electrocardiogram (7 and 8) Timing and coding channels.

Borman's EEG (4 and 5) show rapid shift from wakefulness to brief drowsiness, followed by rapid reversion to full wakefulness. Drowsy period lasted approximately 15 seconds and was characterized by "spindles" of waves in EEG.

Dr. ADEY. Here is an example of Borman 500 minutes after launch, and the two channels marked EEG-1 and EEG-2 from scalp leads on Borman. This incidentally is part of the only brain wave record ever taken in the U.S. manned flight space program, and it shows how, from being quite wide awake, he suddenly exhibits the stage of what we call spindling in the EEG. This indicates the extreme drowsiness and light sleep. Then suddenly he was awake again. These shifting behavior states in the monkey were also accompanied by marked lability of heart rate, blood pressure, and respiration—phenomena also seen in Borman.

For the first time in man or animals, pendular eye movements were recorded in the first 3 days of weightlessness and indicate a vestibular-ocular disturbance.



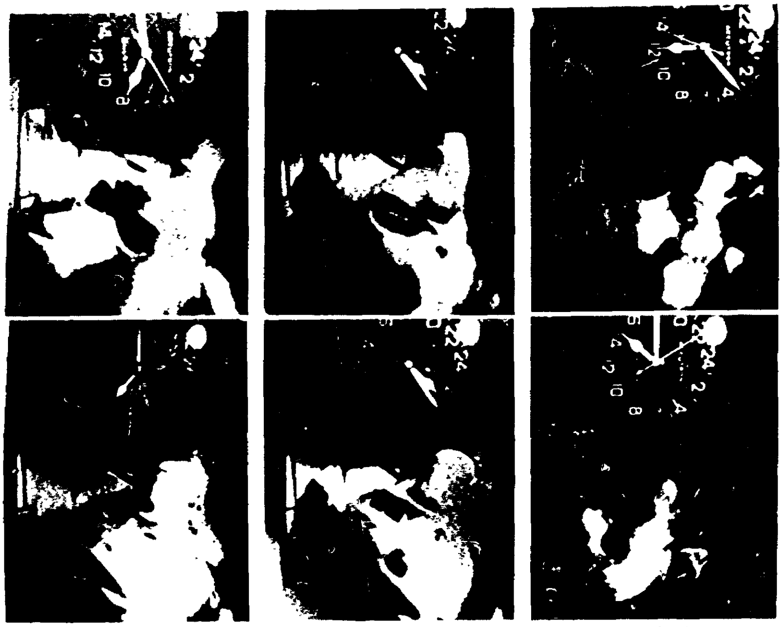
"The eyes swung slowly and rhymtically (R & L EOG) . . . they ceased abruptly, often with strong activity in the trunk muscles (Torso EMG). . . ."

Dr. Adey. The two top channels marked EOG are the movements of right and left eyes. The eyes swing from side to side at a rhythmic rate of about once a second, and those movements in the animal were often accompanied by what you see in the third channel. This channel is a measure of muscle activity in the trunk, and indicates a brief struggling episode as though he were swinging suddenly from side to side.

We have seen this occur in the camera records taken at the same time and it indicates to us an aversion to these eye movements. I would point out that they are often associated with a feeling of nausea. Nausea has been reported in the Apollo flights where, for the first time, the astronauts are able to move more freely in a larger volume.

We will continue detailed analysis of nervous and cardiovascular data for many months, but it should be emphasized that while the monkey retained all the basic features of his terrestrial pattern, there were important and continuing perturbations in these systems.

BIOSATELLITE III



Six frames from the on-board camera—day 3 photos, one awake and the other asleep; on day 5, during DM task session; and on day 7, cheek pouches filled, and 2 hours later, pouches empty.

Dr. Adey. This is a series of frames from the flight camera and the two left frames above and below were taken on the third day. They show the monkey awake above and sound asleep below.

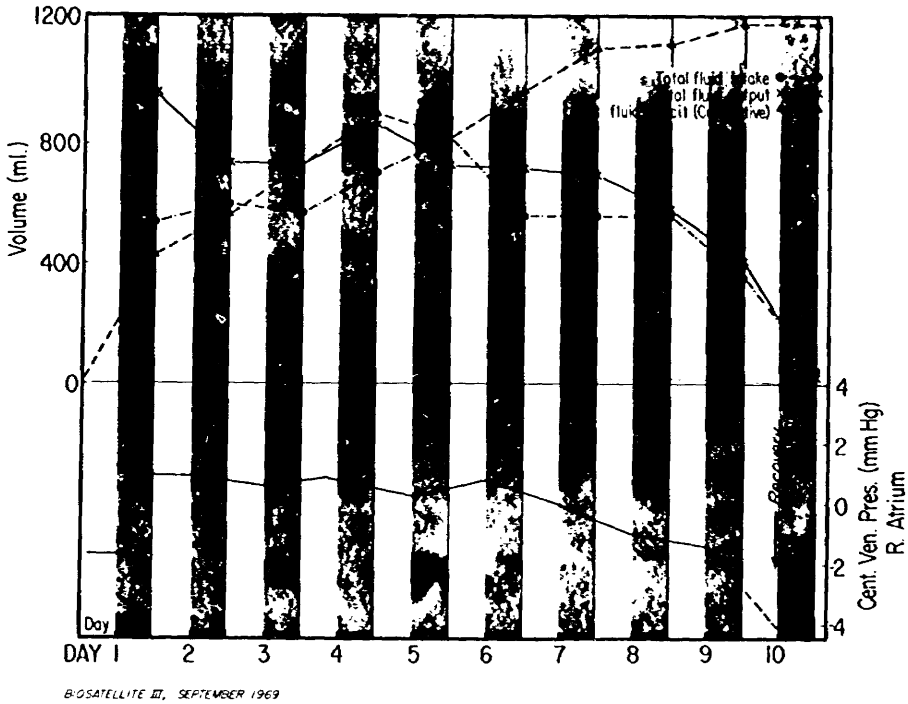
Then on the fifth day, the frames were taken at a much faster speed. The camera took normally a picture every 20 minutes, but during the task performance experiments it took four frames a second, and the two frames you see there were during the four-frame-per-second activity and they show the monkey's eye movements as he did his assigned tasks.

On the seventh day, the top frame shows the pouch filled with food and then another frame a few hours later shows that all the food in the pouch had gone and presumably was swallowed.

The details of these records are sufficient for us to give very detailed analyses of the test performance data and the general states of sleeping and wakefulness.

Next, I want to discuss briefly next the factors which we consider to have contributed to the physiological deterioration of the flight monkey.

The following brief account of circumstances leading to the animal's collapse implicates weightlessness as a prime factor and is relevant to environmental constraints, task requirements and mission durations currently planned for manned space flight.



The fluid loss has been calculated from both spacecraft data and animal pre- and post-flight body weight. The central venous pressure was obtained from USO data.

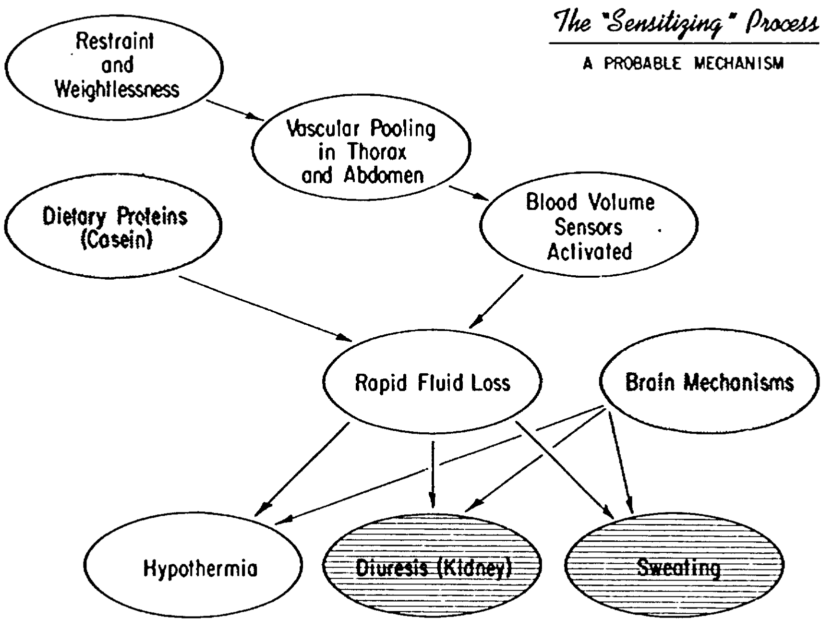
With the onset of weightlessness, there was a rise in central venous pressure measured in the right atrium of the heart from a normally negative value seen on earth to a sustained positive level. This is interpreted as indicating a pooling of blood in central venous structures of the trunk. When distended with blood, these venous structures initiate nervous and hormonal reflexes to eliminate the excess fluid through the kidney and by sweating.

This, Mr. Karth, is data gathered by Dr. Meehan, and he can speak to it directly.

The animal's net negative fluid balance over the 8-day period, shown in the top part of the graph, measured from water intake and excretion, was about 1,200 milliliters, or 20 percent of its body weight. This involved perturbations in body fluid balance, electrolyte metabolism of sodium and potassium, and ultimately, the stability of the cardiovascular system.

The potential hazards to man in these mechanisms has been recognized in a medical planning document prepared by the Manned Spacecraft Center in May 1969, which states that:

"Volume receptors which respond to vessel or heart chamber wall stretch are stimulated by shifts of fluid within the vascular spaces when gravitational forces are removed or decreased. Through neuroendocrine pathways, a diuresis is initiated and the total water content of the body is reduced. This results in partial dehydration of body tissues and reduces the capacity to respond to stress."



BIOSATELLITE III, SEPTEMBER 1969

If I could just briefly indicate the factors as we see them in their progress and succession, at the top we have restraint and weightlessness together contributed to vascular pooling in the thorax and abdomen. We think we can separate the factor of restraint from weightlessness, because the measures show this animal in flight lost considerable more weight than the control animals on the ground under the same conditions, and the data from the spacecraft indicates that the flight animal lost a major part of the fluid by sweating and the control animals on the ground did not so lose the water by sweating. The loss they experienced was by the kidney primarily; so that we think we can separate the restraint and weightlessness factors.

Then the pooling of blood in the thorax and abdomen leads to activation of blood volume sensors and rapid fluid loss, and this rapid fluid loss is partly diuresis through the kidney, partly through sweating, and at the same time the brain mechanism is activated which leads to the exaggeration and enhancement of all three factors: Sweating, diuresis, and ultimately loss of body temperature.

We include one additional factor which we feel requires evaluation, in terms of the severity of the changes. The diet given the animal had casein as its sole source of protein. This was necessary to keep the urine acid in order that the urine analyzer would not be rendered inoperative through deposition of calcium from an alkaline urine.

It was decided that rather than to acidify the urine after it left the animal, we would ensure an acid urine through dietary measures and safe operation of the urine analyzer.

However, a total protein intake of casein may have some influence on the ability of the animal to withstand the stress of fluid loss, and

this is being investigated from the point of view of ground-based experiments.

Mr. KARTH. Eventually he would not be able to withstand the stress of fluid loss irrespective, would he?

Dr. ADEY. We assume that the level of the fluid loss in this animal was something that dietary factors alone would not have prevented. It occurred independently of dietary factors and, as Dr. Meehan will show in his data, the fluid loss was very heavy at the onset of the flight which is similar in that respect to the data from the astronauts.

It is my understanding that the maximum fluid loss from an astronaut has been around 7.8 percent, and amounted to 16 pounds in body weight in a 3-day period. This occurred early in the flight.

Mr. KARTH. During what; the first 3 days you said?

Dr. ADEY. The first 3 days of flight.

Mr. KARTH. After that, it became a normal fluid loss?

Dr. ADEY. I am not aware of whether this continued the downward course, but the comparison of his prelaunch weight with his weight at recovery enables one to say he lost that amount in the early days of flight. We have figures in Dr. Meehan's data which indicate that in the monkey the loss was heavy early in the flight.

It is in the resistance to stress that a cautious attitude seems warranted in planned flights for man. Marked distress with rapid heart action and respiratory embarrassment have been reported in man on exercise during extravehicular activity. The well-documented sequence of events leading to collapse in this monkey suggests the need for a guarded approach to design of missions for man that might involve extreme effort after considerable exposure in weightlessness.

Mr. MOSHER. Mr. Chairman.

Mr. KARTH. Mr. Mosher.

Mr. MOSHER. You say "suggests the need for a guarded approach to design of missions for man that might involve extreme effort after considerable exposure in weightlessness."

Are you considering any recommendation for the requirement of artificial gravity in future spacecraft?

Dr. ADEY. I don't think that type of recommendation comes out of this type of flight, Mr. Mosher. I think the question is one which must be settled in relation to man himself. However, I would suggest that the required data on man's ability to perform severe physical efforts or highly coordinated motor movements on exposure in weightlessness, this has not been tested and should be tested very thoroughly as a required objective before one considers the incorporation of artificial gravity.

If we are to speak in the frame of a requirement for artificial gravity, there is no data available for animals or man that would say that a tenth of a g. or a sixth of a g. or a quarter or a half of a g. represents the necessary minimum to prevent deterioration either in the cardiovascular and blood volume area, or in the area of motor performance.

In other words, the combination of data from animals and man should indeed include exposure to varying levels that represent the levels that might be built into a space station or a space platform; but at this time, there is no evidence that will help us in that direction.

Mr. MOSHER. And to obtain that evidence would take a lot of time and a lot of effort?

Dr. ADEY. It would take some very carefully planned and extremely well-controlled experiments. One should also point out that there may be differences in the gravity needed for this purpose between, say, a monkey and a man.

Mr. KARTH. Doctor, you used the words "extreme effort." I am sure you are aware of the fact that exercises are planned for longer duration flights as well as exercises I think that were initiated and performed by the astronauts during their last flight, and obviously these will be executed in the flight scheduled for the very near future.

Is that what you are talking about when you say "extreme effort"? Is that, in your judgment, something we ought to be very careful of?

Dr. ADEY. I think the imposed exercise regime can be kept under medical control, presumably from the ground, during the actual performance. I would like to make two comments. One is that to be meaningful, exercise is something that should be done under conditions where the actual work performed can be measured and pulling on a bungee cord is not a controlled form of exercise. One must know exactly in measured engineering terms how much work was done, what energy expenditures the man put out in calories and what oxygen consumption and so on he required to perform that exercise before one can speak meaningfully of a controlled experiment.

I am not aware of the protocols for the proposed experiments, but if these requirements are not met, I submit that the experiment is not meaningful.

Mr. KARTH. It might even be harmful; is that what you are really suggesting?

Dr. ADEY. It may be harmful to man; but we are not getting data from which one can say that a man who performs at a certain level on earth is reduced or altered in a certain way when he performs that exercise in space. There should be a direct comparison between information collected on an individual on the ground and his ability to perform that same exercise, or a comparable exercise, in space.

Mr. KARTH. But, as I understand it, these controlled exercises have been devised to eliminate deleterious effects of weightlessness which obviously astronauts experienced when they were in space flight.

What are you saying really in regard to these exercises?

Dr. ADEY. That the nature of the exercise is something that can be imposed in a way that is medically desirable, as you have just indicated, as a therapeutic or prophylactic measure. It is also something imposed so that data can be collected for a biomedical or bioengineering purposes indicating how much work man can do. The latter can be collected not only in a laboratory experiment, but also in terms of an operational exercise.

There has been one very useful example of an operational exercise in which there was an attempt by Astronaut Gordon to put a tether over the Agena in the Gemini 11 flight. Despite his practicing this exercise in aircraft in free fall and his apparent ability to do it in a matter of seconds, he was quite unable to perform this in a matter of minutes in the space environment. Moreover, he suffered severe physical distress with rapid heart action.

The steps that were taken in Gemini 12 by training the astronauts under water, by offering foot restraints and hand holds, represents an operational approach to the performance of tasks; and if we are

speaking of men working in space platforms and space stations, where presumbly quite difficult operational exercises will be or could be imposed upon them, it is surely desirable to know to what extent their performance is sustained or degraded when they perform these tasks in space.

In summary, I don't see exercise testing as a simple single entity. I think it is an extremely complex matter of man's operational capability in his environment.

Mr. KARTH. What you are saying is we really ought to be doing some controlled experimentation with this before we just go ahead and devise certain exercises without controlled experiments?

Dr. ADEY. Yes, sir.

If I might proceed to some of the more philosophic aspects of the problem of acquiring biomedical data in space, to this time, biomedical data from the U.S. space program has been confined almost solely to observations in manned flight. These data may be claimed as "survival parameters," monitored in such simple data as heart rate, respiration and intermittent blood pressure measurements. More sophisticated data have been acquired sporadically in daily caloric intake, fluid balance, urinary steroids and brain wave patterns, together with measurements of blood volume and bone density.

It cannot be too strongly emphasized that we are very far from the broad and deep biomedical baselines on which to confidently design space vehicles for prolonged human occupancy in either earth orbital or interplanetary missions now under review for the post-Apollo period.

Sir, if I might just refer to this document which I understand has been given to the committee, it addresses itself to the biomedical foundations of manned space flight, and makes that statement explicitly.

Mr. KARTH. I have not had an opportunity to read it. I just got it this morning as I walked into the committee room. With no objection on the part of the committee, it will be printed in the record just preceding this day's testimony, as I announced earlier this morning.

Dr. ADEY. Granted that much better biomedical data can and will be gathered in future manned missions, such as the Saturn workshop of AAP, there can be little doubt that some of these baselines should also be acquired by biosatellite experiments. They will have greater precision, and a cost effectiveness indubitably superior to halfhearted attempts to "add" medical experiments to manned missions with quite other primary goals.

The present limited series of biosatellite flights has brought us to a major crossroad in such investigations. These flights have necessarily adhered to the philosophy of "integrated experiments," a concept necessarily imposed by weight, volume, and power constraints of spacecraft available at the program inception 5 years ago, but one from which early and complete escape is essential.

Integrated experiments have many points of contact with spacecraft systems. Thus, once they have been accepted as flight experiments, they cannot continue to evolve in the experimenter's laboratory and be delivered shortly before flight as self-contained "modules" for final integration with spacecraft systems. In consequence, investigators in the current biosatellite program have seen their experiments frozen in the instrumentation technologies of more than 5 years ago, unable to make a single change without facing dire and even disastrous expense in modification to flight hardware already procured.

Acceptance of the modular concept in future studies on both man and animal would appear inevitable. Not only will it allow continued development of optimal methods for a particular experiment until late in the preflight phase, but its cost is a fraction of integrated methods. Along with the modular concept, larger booster systems now available and prospects for an earth-orbiting space station make possible totally new schemes of biomedical data acquisition in animal experiments:

1. Orbiting a series of animals, ranging from sizable colonies of small mammals to subhuman primates, in a single payload for extended periods (6 to 24 months). Increased reliability of automated systems makes feasible such operation with unmanned systems.
2. Orbiting a smaller number of animals in an unmanned system with special environmental characteristics, such as varying but known artificial gravity levels (using a centrifuge). These G-levels would be both imposed and selectable for different subjects. Similarly, life support systems could be selectively tested for effects on known physical workloads and imposed psychological and physical stresses.
3. Participation by man in such operations in a space station. His role might range from simple daily dial reading of data from totally encapsulated experiments, to major daily interaction with test subjects. Man's role is obvious in detection of experiment anomalies, in manipulation of experiment conditions based on frequent observation, and in data analysis where needed for concurrent experiment modification. Refurbishment of long-term experiments is possible in the space station concept.

In summary, future flight programs should offer vastly improved opportunities for good biomedical data acquisition over that available in previous manned or unmanned missions. Biomedical investigations in animals in space flight appear to merit most serious consideration for formulation on a program basis. No single biological experiment can ever offer complete answers to an important question, by reason of the inherent complexity and variability of living systems.

Mr. Mosher. Mr. Chairman.

Mr. Karth. Mr. Mosher.

Mr. Mosher. The witness seems to be recommending a biosatellite program that is far more complex and far more comprehensive than anything NASA or we have contemplated before.

Is that the burden of your recommendation?

Dr. Adey. That is correct, sir. The advice offered to NASA by the National Academy panels, by PSAC panels, and by advisory panels to NASA itself, dating from 1960, have all emphasized the need for a broader and deeper series of biomedical investigations.

Mr. Mosher. Are you suggesting that these broader and deeper biomedical investigations are essential—imperative to the success of future manned flights, so that we shouldn't go ahead with hardware, and so forth, for future manned flights until we have done these investigations?

Dr. Adey. Yes, sir. I think I interpret your question as follows, and concur in it to this degree: That we need considerably more biomedical information before we could plan the generation of spacecraft that would be necessary for interplanetary flights, for instance, and in leading to that goal, through space platforms and space sta-

tions, the volume and depth of biomedical knowledge needs to be increased manyfold. This again is an opinion that is firmly stated in this new USAC document.

Mr. MOSHER. In addition to the question of useful knowledge, is the actual safety of men involved a factor in your recommendation?

Dr. ADEY. The safety of man requires that the extension of duration in orbit be conducted on the basis of a broader type of biomedical information about each astronaut in orbit than has been the case hitherto for the reason that many of the degradations we anticipate will occur will be subtle; and unless there is a continuing body of medical evidence about each individual, the subtle nature of the degradation may reach levels at which he is no longer able to sustain himself as part of the mission without that fact being clear in the control of the mission.

Mr. MOSHER. So you are really waving warning flags, go slow flags, at this point?

Dr. ADEY. If it is a question of man's ability to go in the missions immediately planned as the first steps in the Apollo Applications for 28 and 56 days, I think these can be planned and probably executed if there is sufficient instrumentation on the man.

To the 28-day flight, I would speak affirmatively. I think that it is essential in the 56-day flights for planning to take proper account of results of the 28-day mission.

Mr. MOSHER. In other words, we shouldn't commit ourselves completely to the 56-day flight without knowing what happens in the 28-day flight and examining the data there pretty carefully?

Dr. ADEY. No, sir.

Mr. KARTH. Would you care to describe what you mean by "sufficient instrumentation," Doctor?

Dr. ADEY. Well, the first requirement is that we get objective rather than subjective measurements of the broadest aspects of sleep and wakefulness. I submit that it is not enough that the astronaut himself report on how many hours of sleep he has had, nor on the quality of sleep, nor is it enough that the ability to perform the task be estimated solely on the astronaut's estimate of whether it was effectively and efficiently performed.

Mr. KARTH. Does this require implantations?

Dr. ADEY. No, sir. The instrumentation we would have in mind would be on the surface, and I would point out that there is a great need for major bioengineering programs to develop better instrumentation in this field.

One of the great weaknesses currently is a lack of appropriate bioengineering capability. But speaking to the 28-day flight, I think enough information can be monitored. This should include aspects of urine analysis and again flight urine analysis techniques will need to be substantially improved if they are to provide the quantity and type of information that is needed.

Mr. KARTH. All of these recommendations, Dr. Adey, for better control and more comprehensive biological experimentation and research for prolonged flight, what is the reason, in your judgment, for these things being turned down out of hand by NASA?

Dr. ADEY. Well, sir, I think this really relates to the operational requirements.

Mr. KARTH. They have been rejected. We don't have a program.

Dr. ADEY. Yes; my personal opinion is that in the Mercury and Gemini programs, the mission objectives were set primarily by engi-

neering considerations and the requirements of man were to perform within a system in which the spacecraft was assumed reliable, and his role in it was that of an operator. He was not in a situation where extended exposure to the environment itself might represent a hazard. We were working with flights no longer than 14 days, and in the incremental way this was approached by NASA, the ability of man was proved, but no major measurements were made.

If one looks at the history of medical measurement in the Gemini program, toward the end of the program, it was substantially improved in amount of information and in the nature of the measurements.

With the imperatives of the Apollo mission itself to get man to the moon and back, this type of measurement ceased to be made and currently we are basing our opinions, as far as firm data goes, on data that was gathered in the Gemini program primarily.

Mr. KARTH. In other words, you feel we made some rather precipitous judgments and took some chances that you, as a medical man, would prefer not to take in completing the Apollo objective. Is that what you are saying?

Dr. ADEY. Yes. In the first place, there has not been the opportunity to qualify man in the way that the hardware has been qualified in the engineering sense. In other words, the engineers have very appropriately qualified their engineering systems. We have not qualified man as a system or as part of the engineering system, and the PSAC document directs attention to the fact that the role of man in future requires his qualification in this sense.

In speaking of qualification, one should not think of man merely as surviving in space for extended periods, but that the qualification should involve his ability to perform at a high level physically and mentally throughout those periods. It is in moving into this qualification procedure involving precise estimates of physical and psychological capability, that we are now on the threshhold of a requirement for which there is very little if any baseline.

Mr. KARTH. We can be so careful we would never get anything done. Your position is not one of that type of carefulness; is it?

Dr. ADEY. Absolutely not. I categorically place myself in the position of those who would see man going into space for indefinite periods, but supported appropriately, and my concern is with the level of support that is necessary in order that he go and sustain himself effectively.

Mr. KARTH. To your knowledge, is your position supported by a major portion of the medical community, would you say?

Dr. ADEY. I think, sir, that I would limit it to saying that my position is that which is taken by this PSAC advisory panel, which included members of the medical profession and was drawn with great care from representative sections of the profession.

Mr. KARTH. Yesterday the question came up about the well-engineered aspects of the hardware in which the astronauts are being carried into outer space, to the effect that the engineers say it is 99.966 percent fail-safe.

The question was raised as to whether or not the good and welfare of the astronaut; that is, the deleterious effects upon his health, was equivalent to the engineering fail-safeness of the hardware, that is, 99.966 percent.

Do you feel it is?

Dr. ADEY. No, sir; I don't think it is. The engineer has aimed at insuring man's survival, but the question of capability and comfortable living in the frame of long term——

Mr. KARTH. His survival, insofar as the performance of hardware is concerned, that is what the engineers have sought to make 99.966-percent safe. They say it is and I trust their judgment. They are a very competent professional group of people.

My question really is, Do you feel that the health of the astronaut is 99.966-percent safeguarded?

Dr. ADEY. By the hardware?

Mr. KARTH. By biomedical or biological engineering that has been done, along with the hardware engineering.

Dr. ADEY. Yes, I think he has been very well protected in the missions of the duration that have been flown so far; but when we are speaking of the extension of these missions by factors of six, eight, ten times, then I submit that the engineering know-how does not extend into that area and that engineering know-how to support man appropriately may very well need a rather thorough reexamination.

Mr. KARTH. His health from the physiological sense, Is it 99.966 percent guaranteed, if you will, for the missions that we are now performing and those we have planned for the immediate future, like the hardware is guaranteed 99.966 percent?

Dr. ADEY. Well, sir, I am not an engineer, but a biomedical man looking——

Mr. KARTH. I am talking to you about the safety of the astronaut from the medical sense, from the physiological sense, not about whether the vehicle is going to crash or something go wrong with the hardware so that his life is endangered. Strictly from his own health standpoint and the precautionary measures we have taken to guarantee that—his physiological well-being and his psychological well-being—do you feel that is 99.966 percent guaranteed to him on the basis of the experiments we have gone through in those fields, the same way as the engineers feel that the hardware is 99.966 percent fail-safe?

Dr. ADEY. Well, my answer I think should be that on the basis of the existing vehicles and man's occupancy of them there is not a guarantee that he would be safeguarded in all respects beyond the 28-day period. I suggest that for the problems that would face him beyond 28 days we do not have sufficient data about his psychological well-being, nor about his physiological status in a totally weightless condition; and if the engineering envisages weightless systems, then we cannot speak with any predictive value beyond a 28-day period.

Mr. KARTH. Would you feel secure in his physiological and psychological well-being for the 28-day flight on the basis of the lack of experience we have in the biomedical field?

Dr. ADEY. By no means, I think that within the 28-day period we may face some problems, but I think that in the medical statistical process of looking at a healthy man and putting him into orbit, watching what happens to him, and knowing that some deterioration will occur, the chances are still good that he can go for 28 days.

Mr. KARTH. But you feel the 28-day flight should not be undertaken unless we have sufficient instrumentation on man himself during the 28-day period.

Dr. ADEY. I would take a strong position on that. It would be a worthless flight in the medical sense if it were flown on the basis of the astronaut metaphorically pounding on his chest and saying, "I am fine." If that is the level of data that comes back from the 28-day flight, with the prospect of the man saying that he is fine and no specific data on the urinary steroids, no precise information on circulating blood volumes, no precise information on the work-rest cycle effect on his circadian rhythms—if this information is not gathered in an extremely precise way, then I think the effort is largely wasted.

Mr. KARTH. Have these experiments been well defined at this point for the 28-day flight to your knowledge?

Dr. ADEY. I know that there are some quite well-defined experiments.

Mr. KARTH. Are they sufficient in your judgment?

Dr. ADEY. I think that if the manned space medicine group had their wishes they would be considerably more extensive than they are currently.

Mr. KARTH. Could you delineate for the record what additional instrumentation or safeguards or experimentation ought to be conducted during that flight in addition to what they have now planned for it?

Dr. ADEY. I think, sir, this is more——

Mr. KARTH. You don't have to do it right this minute. This might be difficult for you to do, and I appreciate that, but before the day is out if you could supply it for the record so we will have it tomorrow morning.

Dr. ADEY. I would like to try, but I think this is really the province of the space medicine people to have an opportunity to express what they consider to be some of these experiments. After all, they are very close to the vehicle constraints and I am not. The nature of the vehicle itself will determine the nature of the measurements because this is a prime example of man interacting with a specific environment; and the most meaningful experiments are those which estimate him as a performing individual in that environment rather than taking him away to do busy work and to do tasks that bear no relation to the operational requirement.

Mr. KARTH. Now that I am sufficiently confused, you want to proceed, Doctor.

Mr. MOSHER. Could I interrupt?

Mr. KARTH. Mr. Mosher.

Mr. MOSHER. Going back to the necessity, and I judge the imperative necessity, in your mind of obtaining more preliminary data before long flights, do you contemplate that this should best be done by a series of unmanned satellites or would it best be done with animals on manned satellites or what?

Dr. ADEY. Sir, I think both would represent desirable goals. In other words, as I shall indicate in a moment, we should choose manned or unmanned operations strictly in the frame of the measurements we propose to make and the optimal way in which they could be made.

It may well be that the presence of man represents an intrusion on the experiment which we would do well to avoid. It may be that the experiments themselves, in some instances, are so complex that man is essential to have an overview of them on a day-to-day basis.

In terms of what to do next, I think the opportunity should be taken to formulate a program in which there are unmanned flights

of considerable numbers of smaller animals for quite extended periods, and that these would have value in laying foundations for some very broad and much-needed information about circadian rhythms, for example. But, when we come to the high-level mission, when measurements are to be made of cardiovascular functions, and of brain functions in sensory perception and so on, rather than to do what was done in Biosatellite III, where a very large number of measurements were made in one animal, we should be making more refined and fewer measurements on each subject and thus flying more subjects.

So I believe the philosophy will trend toward multiple subjects in a single flight.

Mr. KARTH. Mr. Koch.

Mr. KOCH. Yesterday, when Dr. Reynolds was before us, he made it very clear that there was a good deal of medical information yet to be ascertained from the testing on the monkey from that last laboratory test. When Dr. Reynolds was interrogated by us and asked whether, well, how long will it take to finish these tests, he thought by January, working a regular 8-hour day. We further interrogated him and asked, ought we not wait until the outcome of those tests and even take some more comparable tests before we put men in space for 28 days. He said, no, it wasn't necessary.

I think I paraphrased that correctly. I notice some nuances in terms of your testimony. For example, one, you indicated if it were to go beyond 28 days, there is no question in your mind we ought not to do it before we had more information, biological and scientific, as to what would happen to men; and then you used a word which was with respect to the 28-day flight which was that "probably" it was all right.

I think that was the word you used. Now, when I practiced law as a trial attorney, you could never ask a doctor to guarantee any correlation or connection between a trauma and a disease or some other manifestations in man, but you could have the right to ask him whether he could say, with reasonable medical certainty, that something had occurred.

I ask you whether, with reasonable medical certainty, you could assure us there would be no adverse effects upon these men if they were to travel for 28 days without further testing on our part, your part specifically, of animals in advance of such a trip.

Dr. ADEY. Thank you, sir. [Laughter.]

I will try and be very brief.

The question of man going for 28 days, I think, is probably within the realm of current capability. To answer specifically the first part of your question as to whether deleterious effects will occur, I will say with absolute certainty there will be deleterious effects. If these are of a degree that would impair the mission or his chances of survival, then something will need to be done of a preemptory character to terminate the mission.

My estimate of that happening is that it is something less than even, but that is just like betting at the race track, and I don't know.

Mr. KOCH. What you are saying is that you could not say, with reasonable medical certainty, there would not be and I want to even qualify it a bit further and say there would not be gross medical adverse effects upon these men? Because if we were to think in terms

comparable to the race track the odds might be even—the odds are generally against you at the race track—ought we to place men in a situation where you could not categorically state with reasonable medical certainty there would not be gross adverse effects upon them if we put them in this 28-day flight?

Dr. ADEY. I think I would agree that we should not put them in a position where the gross effects are occurring; but if the medical instrumentation is well done, then that data available during the actual flight should have predictive value for the next few days, and on that basis, you should be able to tell when something catastrophic is going to occur 3 or 5 days ahead.

I submit that it needs much more detailed evaluation on a day by day, even hourly, basis and that has not been done in the past.

Mr. KOCH. We also ascertained yesterday that the decision to bring back that poor monkey was a delayed decision. They didn't know whether to bring him back or not to bring him back. There was no immediate decision to bring him back.

Dr. ADEY. Yes, the decision was taken over not longer than a 12-hour period.

Mr. KOCH. All right, there was a period of flux there for, say, the 12 hours you are talking about.

Dr. ADEY. That is right.

Mr. KOCH. And also it was brought out yesterday that the calibration of the instruments which you had did not foresee in advance that the differences in whatever they were measuring would be so gross that that particular machine wasn't in fact even able to measure the sudden change in what was occurring in that animal.

I don't know the name of the machine, but that was testified to yesterday.

Mr. KARTH. There were three different experiments.

Mr. KOCH. In three different experiments, so they weren't, in fact, able to ascertain what was wrong with that monkey for 12 hours, in order to make that decision. Even after they made the decision, the machines weren't able to correctly gage what was happening to the monkey.

Now, it would appear to me that if there is any reasonable doubt, if you are not at the point where you can say with reasonable medical certainty that these things won't happen, then I ask you again the same question I asked the gentleman yesterday, what is the rush? Cannot we wait until January of next year, which is what, a bare 2½ months away, to ascertain at least what the medical information is that came out of the last testing; and if you decide you had to have more testing, at least you took that opportunity. What is the rush?

Dr. ADEY. The rush, sir, is something which is not the slightest connected with any aspect of the biomedical concern. It is the engineering aspect of getting ready to fly the 28-day spacecraft. The leadtimes are long in all aspects of current space flight to prepare well in advance the hardware for the biomedical measures, the motor for the boosters, and so on. These represent such a closely dovetailing set of dates that to say now you are going to delay something in favor of getting biomedical information must be considered in terms of total mission cost, and we, who are close to the biosatellites, know very well the cost of these delays. It is extremely expensive.

Mr. Koch. If the monitoring systems which you told us were necessary even in this particular flight were not all that you wanted them to be, you wouldn't hesitate to say, cancel it, would you?

Dr. Adey. Cancel what?

Mr. Koch. The flight. You already told us that man has to be monitored by instruments very carefully, much more than might have been expected with that monkey, if they go on this 28-day flight; and if those instruments are not all that you want them to be at this moment, you wouldn't hesitate to say stop?

Dr. Adey. That is right, and, as a matter of fact, I think you would do well, sir, to address your questions along this line also to the space medicine people, because I would feel some concern, knowing the approximate flight date for the 28-day flight to be some time early in 1972, as to whether needed instrumentation can be available by that date.

I have no knowledge, one way or the other, but I would feel concerned to know that this is indeed a priority matter in saying when that flight should go.

Mr. Koch. Thank you.

Mr. Karth. Doctor, we all understand the additional dollars that are involved when you can't keep a program on stream, when it is sporadically interrupted, a stop today and a start next month and a stop maybe 6 months later and a start 3 months after that and so on. But do you think the additional dollars involved are a reason for taking the chances involved?

Dr. Adey. No, sir; I think, however, that it is worth looking at the way in which dollars are being allocated to biomedical needs as a segment of the total NASA program. The fraction is far below what might have been reasonably expected in terms of the potential and actual importance of biomedical measurements on man and animals. It is far too low a proportion of the total NASA budget in the manned space flight area, for example.

Mr. Karth. This subcommittee, as you probably know, and then later the House of Representatives, reversed NASA's decision with respect to the cancellation of the last biosatellite flight. From what you said, I assume you are in agreement with the action taken by this subcommittee and in disagreement with the agency.

Dr. Adey. Sir, that is an extremely complex position. [Laughter.]

Mr. Karth. It is not complex at all, not compared to your profession.

Dr. Adey. I would support that merely to fly the second biosatellite in exactly the same form as the first, might not be the optimal way to make the experiment, nor to spend the money. I was one of the people who felt that perhaps we should take advantage of experience in the first flight to make some changes in the second before it was flown. The money that was voted after your kind consideration of the problem probably would not have been enough to carry through the necessary or at least some desirable changes in the spacecraft.

Mr. Karth. It would have kept it alive.

Dr. Adey. Yes.

Mr. Karth. In 3 months, we could have given you some more.

Dr. Adey. May I quote you?

Mr. Karth. Now you are dead.

Did I understand you to say, in answer to one of Mr. Koch's questions, that you feel 50 percent sure, or more than 50 percent sure, that there will be gross deleterious effects upon the astronauts during the 28-day flight?

Dr. ADEY. I am not a lawyer, sir, but what do you mean by gross? [Laughter.]

Mr. KARTH. What my colleague meant, Dr. Adey. Ask him to explain.

Mr. KOCH. I think the question was, can you state, with reasonable medical certainty, there would not be gross adverse medical effects upon them.

By gross, I would mean more than a change in respiration; in other words, something between a great discomfort and death. [Laughter.]

Mr. KARTH. I was trying to be fair with you. That is lawyer language. [Laughter.]

Dr. ADEY. Sir, I think the level of incapacitation will be substantial, in the ability to withstand the changes in reentry and immediately thereafter. This is one area where I would feel considerable concern. I would also be much concerned about the sleeping cycles and the ability of the man to perform well in consequence.

I would also have some concerns about the effects of emergencies. Though we hear, as Mr. Karth points out, of the reliability of the spacecraft, if this is not so and if something does happen on the 25th day, we should ask the question is the man then capable of salvaging himself, let alone the flight. This is the medical uncertainty in its worst reality.

It is very similar to what confronts the armed services in deciding when a man is combat ready, and for what period he will sustain in a condition of combat readiness in the fact of gradual degradation of his environment; or, if a sudden emergency appears in that environment, how will he perform?

Mr. SYMINGTON. Mr. Chairman.

Mr. KARTH. Mr. Symington.

Mr. SYMINGTON. Is that conclusion derived entirely from the monkey's experience, or to some extent from the 14-day manned flight?

Dr. ADEY. To some extent, from all of the data that is currently available from manned flights.

Mr. SYMINGTON. If you had the monkey's experiment before the 14-day flight, would you have felt comfortable about sending them up for 14 days?

Dr. ADEY. May I suggest that your question really relates to the ability to extrapolate from the monkey to man. Is that the way in which you would like to have me answer the question?

Mr. SYMINGTON. Yes.

Dr. ADEY. Of course, we have thought about this a great deal since the flight, and I think the consensus of our opinion is this: That the astronauts have all suffered in some degree from those changes that led to the great deterioration in the monkey. What we do not now know is whether man, in longer exposure to space than he has had at this time, will adapt effectively and retrieve the deleterious changes, will he eventually come out on a plateau that represents a satisfactory level for his performance in space? Nor do we know whether this plateau of retrieval is at a high enough

level for the reentry to 1 g. after a period of 28 days or more. We don't think the level of danger there is such that one should say, don't go on the 28-day flight.

To answer your first question about whether if we had known what happened to the monkey we would say to man, don't go for 14 days, no, I don't think we would say that. I think we would say that, knowing what we now know about the effects on blood volume and on circadian rhythms, with very careful monitoring, we would look for what might appear at first to be minor and trivial trends.

I would point out that, on the physiological level, man has not yet really crossed the barrier into a prolonged performance of weightlessness. To this date, his time in space has been merely in the transition period and transition to weightlessness involves some deleterious effects which retrieve themselves and others which continue a downward course.

Mr. SYMINGTON. One last question. A couple of times you have mentioned the problem of rentry. What is the particular character of the possible weakness of the man that would render his reentry dangerous to him?

Dr. ADEY. The prime weakness is in cardiovacular deterioration. Deconditioning is the word that is used for it. I think that question should really be addressed to Dr. Meehan.

Mr. KARTH. Dr. Meehan, would you care to try that one?

Dr. MEEHAN. I will try.

The cardiovascular system is affected by weightlessness; particularly the venous system, the part of the system that brings blood back to the heart.

What we call the venous tone or the ability of the muscles in the venous system to constrict and facilitate the return of blood to the heart, is reduced after a period of weightlessness.

This has been demonstrated in the Gemini flights, and is published in a NASA document right now. The thing that happens specifically is that when the venous system is subjected to hydrostatic loading, that is, when you stand up, blood tends to accumulate more rapidly than normal in the lower extremities. This reduces the amount of blood available to the heart, and you are apt to experience a phenomenon known as syncope or passing out. It is an exaggeration of a phenomenon that can be produced within gravity but made much more acute.

Now, along with this, there are also changes in all probability in the myocardium itself that could well affect the ability of the heart to perform.

Now, this is undefined and is an area that needs investigation at this time.

Mr. KOCH. May I ask another question?

Mr. KARTH. Mr. Koch.

Mr. KOCH. From the testing you had of the astronauts and of the monkey, were there any irreversible changes that had taken place in their bodies as a result of space flight and particularly weightlessness?

In other words, what I am driving at is that it may very well be, at some point you could bring the men back if you felt there was some dangers they were then going to undergo or that they were in, but you do bring them back in time as not to add to those dangers.

Is there something already which has occurred in any of those who have been in space flight that were irreversible in nature with respect to physiological makeup?

Dr. MEEHAN. Not as far as I know. The philosophy I believe thus far in the manned flights, has been gradual exposure, increasing time. As yet, we have not seen man adapt completely to the weightless environment. I don't know now what the final picture of adaption will be, and I don't think anyone can speak to that.

As of the moment, however, there hasn't been anything grossly dilatorious from which the astronaut has not been able to recover immediately on coming back to earth.

I might point out that the business of entering strange environments has been practiced in this fashion through the years. The first balloon flights, for example, were done by gradually increasing in altitude until the factor of lack of oxygen was discovered. It was discovered rather dramatically. A couple of lads were killed trying it. So they found out the hard way.

It has been the result of a combination of observations on man, gradually exposing them to the unusual environment, and then also the careful use of physiological experiments conducted on animals to define the adapted changes that actually occur, and I think if one examines the physiological history of people entering the unusual environment, whether it be altitude or undersea exploration or whatever have you, that you will find this pattern of gradual exposure to the unusual environment on the part of man backed up by and supported very strongly by the careful and well thought out experiment on the animal, the effort being to define and understand the mechanism of adaptations involved, then followed by the development of procedures and methods that permit man to explore and invade this unusual environment.

Mr. KARTH. Dr. Meehan, in answer to Mr. Symington's question, it seems to me you were just kind of bordering on the suggestion that the astronaut might suffer a heart attack upon reentry. I am not medical man enough to really be able to evaluate what you said, but it almost sounded that way. Is that what you were saying?

Dr. MEEHAN. I don't mean a heart attack in the medical sense, but let's say they might have cardiovascular collapse.

Mr. KARTH. What does that mean? You die without really having a heart attack?

Dr. MEEHAN. That is correct. The heart attack is a medical term implying specific injury to the heart as a result of an established bit a pathology. Cardiovascular collapse can occur as the result of many things, and it simply means a failure of the cardiovascular system to serve the heart.

Mr. KARTH. The fact of the matter is, you die both ways.

Dr. MEEHAN. Right. The type of problem the astronaut may have is the type of problem that the individual might experience who has been confined to bed for a long time or the type of problem that the soldier may experience when standing at attention for a long time in the hot sun.

In either of these situations, the blood tends to pool in the lower extremities, and when this happens, the volume of blood available to the heart is reduced. There is apparently a reflex mechanism that will

operate when the blood available to the heart is accutely reduced that actually stops the heart or produces a very low heart rate that is incompatible with the needs of the body.

The individual will lose consciousness and faint and fall on the ground. Now, you have seen this happen, I am sure, and those of us that have been in the armed services have had ample opportunity in these directions. This condition of syncope is a dangerous one, and if you are held in the upright position after you have passed out, you will die. It is absolutely essential that you fall to the ground and allow the blood that has collected in the lower extremities to return to the heart.

So in that moment, the situation is extremely dangerous.

Mr. KARTH. I have explained to Dr. Adev the action the subcommittee took with respect to the last biosatellite program. The feeling of this subcommittee was that first of all we didn't know what the results of the biosatellite experiment would be—the one that was flown—and, secondly, irrespective and in retrospect, wouldn't it have been wise to have flown another, even had it been identical with the one that only lasted 9 days, to either confirm what we found out with Bonnie or to have had a different experience? Wouldn't that have been nice?

Dr. MEEHAN. I may take exception. I would like to have seen some changes in it.

Mr. KARTH. Whatever changes could have been made, probably could have been made without too much of an effort, but even if no changes had been made, wouldn't it have been nice for the money involved to do it again?

Dr. MEEHAN. I felt, at the conclusion of the Bonnie flight, that it was imperative that another one be executed either in that form or in a modified form, and I still do.

Mr. KARTH. I am trying desperately to vindicate the efforts of this subcommittee, and I think I have succeeded.

Dr. MEEHAN. You are very wise.

Mr. KARTH. One other question, Doctor, before you continue—and I know we have harassed you with questions, but we are most appreciative that you could be here.

Getting back to the 28-day flight, knowing what you know about Bonnie and that flight, and knowing what you know about the other flights that have taken place with man, would you say that there is little possibility, moderate possibility, or great possibility that there will be lasting or permanent health effects upon those who make the 28-day flight? Great, moderate, or little possibility of lasting or permanent health effects? I know it is a guess, but what would your guess be?

Dr. ADEY. If they are recovered alive, and I mean reasonably alive, then there is no likelihood of lasting effects. The flight is an incident that is not likely to have lasting effects.

Mr. KARTH. That is the only time I didn't want a yes or no answer to the question, and I got it. Thank you very much, Dr. Meehan. We appreciate your candor. Dr. Adey, would you please proceed.

Dr. ADEY. I will be brief, sir.

I would like to point up the unique significance of the biomedical data gathered in animal flights in relation to man.

As repeatedly pointed out by advisory panels of NAS, PSAC, and of NASA itself, experiments on primates are invaluable in the search for information on performance ability, and on perturbations on the body's great physiological systems-information valid by extrapolation to the needs and capabilities of performing man. The subhuman primate can be instrumented directly in the brain and in cardiovascular, renal and gastrointestinal systems, in ways not acceptable to human subjects.

Herein is the essential justification for these animal experiments. We can define precisely the hourly, daily, or weekly commitment of the subject's time, without intrusion of adventitious or serendipitous factors that are the common lot of the astronaut in competing work schedules and irregular sleep opportunities.

Modern implanted sensing devices, though generally unsuitable for human application for long periods in space, can provide continuous readings of functions in all major body organs, without the need for body restraint. Continuity of data acquisition, direct sensing of functions in deep as well as surface structures, precise timing of environmental manipulations and testing, and the absence of either required or uncontrolled communication with other subjects, are the key notes of good animal experiments in space flight. Their counterpart in observations on man is difficult or impossible to secure. It is a matter of sad record that low priorities accorded medical data acquisition in manned space flight have resulted in a parlous lack of needed baselines for planning future programs.

I would like to speak to the joint development of flight experiments by NASA and academic institutions. Biomedical research within NASA is essentially restricted to two centers. Space medicine at the Houston Manned Spacecraft Center is limited primarily to monitoring requirements in current space flight programs. At Ames Research Center, a powerful research capability exists in many areas of fundamental and applied physiology, but with minimal relationship to present flight programs, manned or unmanned.

For these reasons, and to insure as broad a competence as possible in experiment design and preparation, OSSA, through the Bioscience Program Office, has sought the participation of academic institutions in flight experiments. OSSA alone in NASA has continued to seek and sustain university programs in fundamental and flight directed research.

This point deserves emphasis. The complex effects of the space environment on mammalian organisms demand utmost care in flight experiment design by those with outstanding national competence in fundamental biology and in clinical medicine. OSSA programs have shown great awareness of both national responsibilities and national opportunities in widespread participation of academic institutions.

Participation of academic institutions, in a venture of such magnitude, demands dedication to a single long-term goal with only modest assurance of success. This has discouraged many senior scientists from personal or institutional involvement. It is imperative that NASA recognize its obligations to nurture normal professional development in young biomedical scientists committed to such projects. This requires opportunities for them to participate in research outside the confining frame of a single flight project, and to develop in normally

competitive academic life. For NASA to make a lesser commitment to institutions providing flight program support can only be construed as less than duly responsible in the public interest.

In conclusion, a major, direct and continuing contribution to the medical physiology and psychophysiology of man in space can be made by judicious use of animal experiments, and particularly by studies in subhuman primates. Animal experiments that duplicate conditions of prolonged manned flights can provide substantially more information than studies in man with inherently more limited instrumentation.

Future animal investigations should be planned and executed with close and continued participation of academic research institutions. They will involve many new developments in bioinstrumentation of great value in biomedical research clinical medicine. Their scientific character makes it essential for these programs to sustain their individuality through scientific overview in OSSA, rather than as appendages to programs of OMSF or OART. Their development in flight programs should entail judicious selection of manned or unmanned missions, as circumstances determine.

Thank you, sir.

Mr. KARTH. Thank you very much, Dr. Adey. Is it possible for the witnesses to return this afternoon at, say, 2 o'clock?

Dr. ADEY. Yes.

Mr. KARTH. According to a rule of the House, I have got to get permission for the subcommittee to sit during the time that business is being conducted on the floor. I will seek to get that permission, and feel quite sure I will be able to get it.

Rather than beginning with another witness at this point, so you have time to get some breakfast if you already haven't, I think that we ought to adjourn now and reconvene at 2 o'clock this afternoon.

Unless there are any objections, we will recess at this point, and reconvene at 2 o'clock.

Thank you very much.

(Whereupon, at 11:50 a.m., the subcommittee recessed, to reconvene at 2 p.m., same room.)

AFTERNOON SESSION

Mr. KARTH. The subcommittee will come to order.

Dr. Adey, before we begin and while we wait for other members to appear, I wonder if I could just explore briefly with you some other questions.

I have in my hand the November 12 issue of Space Daily in which there is an article that quotes Cosmonaut Shadolov as saying that the effects of weightlessness is, in his judgment, a very serious problem. Before building orbital stations, he says, one must know how long a man can perform effectively in space, which implies strongly at least they are not going to pursue that course until they have more answers to the medical problem.

Are you at all aware of what the Soviet Union's position is at this time, and what information they have on the effects that they discovered from weightlessness of their astronauts?

Dr. ADEY. Sir, I think most of us who have been in these programs met from time to time with Soviet scientists, and occasionally with their cosmonauts, and we discuss the problem.

There is also available to us a considerable amount of unclassified published literature. The opinion that they offer in the published literature suggests that they view weightlessness as something that affects most if not all the major body systems, and that their approach to it will be by looking at both animals and man.

They have a long record of flying a vast variety of living forms. Often even in the published versions of their work it isn't very clear to us what questions they were asking. I think this is one philosophic problems that occurs. We are not always able to interpret easily the significance of their experiments.

But it does seem clear that they are doing much work in the cardiovascular area, and in the area of performance capability.

When they fly, they make many more measurements on their cosmonauts than we customarily make on our astronauts.

Mr. KARTH. We have an agreement, do we not, mutuality agreement with the Soviets that we will exchange information of this kind?

Dr. ADEY. Yes, sir.

Mr. KARTH. You don't feel that you had answers to all of the questions you propounded?

Dr. ADEY. Well, I think they are very free in their answers to nonoperational questions. In other words, if we ask them directly about cardiovascular activity, they will answer us as best they can. My strong personal impression is that they are not acting in a clandestine way in their measurements.

I think my colleagues here have also had contact with the Soviet scientists and may have opinions about it.

Mr. KARTH. Dr. Pace, is there anything that you could add to what Dr. Adey has said?

Dr. PACE. I had the opportunity to talk with one of the biomedical scientists from the Soviet Union, and I was struck by his remark that they have encountered the same kind of general resistance to animal flights as we have experienced in our history of the space program.

Mr. KARTH. To your knowledge, is the question of weightlessness and the medical problems associated therewith in the opinions of the Russians, at least, the reason for concluding your reasoning they would not have a manned space station for at least the next 5 years?

Are you aware of any association of that kind which might have promulgated that decision?

Dr. PACE. I have no personal knowledge.

Mr. KARTH. Anybody at the witness table?

Dr. Meehan?

Dr. MEEHAN. A month or so ago, I did have the occasion to meet with a group of three people at a meeting of the International Association of Aeronautics and Astronautics at Cloudcroft, N. Mex. We discussed the animal programs at the time, and I was told that they had indeed planned a number of additional experimental flights. We exchanged data from our biosatellite program and their 23-day dog program.

Mr. KARTH. With respect to the medical problems associated with weightlessness, please tell us what reasons were given, to your knowledge, for making the decision they should not have a space station for at least 5 years?

Dr. MEEHAN. They focused on one of the fluid loss problems on the weight loss problem, and there was some considerable discussion on these.

Mr. KARTH. Did any of you read the November 17 issue of U.S. News & World Report? I was just reading it the other night and I happened to cut this out because it concerns itself with the question we are discussing. The title of it is "Risks Facing Man in Space," and it is an interview with Dr. Berry.

On page 59 of that issue, this question was asked:

Most people assume that Bonny died because of prolonged weightlessness. Is that your understanding, also?

Answer. I have not seen the data and can only comment on the experimenter's statement that, "the physiological deterioration of the monkey flown in Biosatellite 3 is mainly attributed to the effects of weightlessness".

The animal was dehydrated and exposed to other stresses, such as confinement in isolation—to say nothing of the instrumentation. Attributing the physiological decompensation principally to weightlessness per se on the basis of this single flight would be apparently unwarranted.

Any extrapolation from the event to future manned space flight is simply unjustifiable speculation.

Do you agree with that?

Dr. ADEY. No, sir.

Mr. KARTH. Do you agree with that, Dr. Pace?

Dr. PACE. No, sir.

Mr. KARTH. Dr. Meehan, do you agree with it?

Dr. MEEHAN. No, sir.

Mr. KARTH. Was there any red cell mass loss noticeable in Bonny?

Dr. PACE. That measurement was not possible to carry out for the reason that Dr. Reynolds touched on yesterday; namely, that the animal died before we could carry out the planned postflight measurement.

Mr. KARTH. One other question was asked, and let me state it: "Question: Just how far will man's body allow him to go in space? Are there any time or distance limits beyond which an astronaut can't go?

He starts out by saying, "That's the question of the century." But then concludes by saying, "We feel that none of these"—he's talking about the physiological changes and so on that they have noticed in the previous flights—"we feel that none of these is a limiting factor, but rather that the changes are evidence of man's adapting his body to the zero g. weightless environment."

Do you agree with that?

Dr. ADEY. I think that there are adaptive changes, but I'm not convinced that they are all changes that will lead to satisfactory ultimate performance capability or even survival. What we do not know now is where many of these adaptive changes end. The flights have been too short to this time to be able to say whether the adaptive changes are indeed truly adaptive or represent trends that may continue indefinitely.

Mr. KARTH. He goes on to say, "Now, we want to extend exposures to duration of 28 days and 56 days, which we plan in Apollo applications flights." That is, "long earth orbiting missions, on which astronauts will conduct scientific and engineering experiments, in 1972.

"We then hope to go further and prepare ourselves for planetary missions like Mars. In order to do that, it is necessary to get information on man in flight for periods of at least 6 months with information

like that in our hands I think we would be willing to extrapolate out the periods of 1 or 2 years.

"The one variable that would still cause concern would be the psychological implications of very long duration flight."

I guess there really isn't reason for me to ask you to comment on that, because he is talking about extrapolating out the periods of 1 or 2 years, I think, on the basis of experience gained on flights up to 6 months. I guess there is no reason to ask you to coment on that.

Mr. ADEY. Sir, may I offer a comment? And that is, that much of the data that has been gathered to date has not been uniform in the direction of change, nor in the amount of change in quite significant paramters, and one must also take a count of the need to have a sufficient number of personnel in space for a sufficiently long period in order that we have a baseline to say that in the average, or over a group of people, this is the most likely trend in a particular circumstance. This really raises the question of the variability——

Mr. KARTH. That is why we wanted to fly two monkeys out there.

Dr. ADEY. Yes, sir. This is why, I think, merely to say if we had three astronauts for 6 months, we have answered all the problems. It is really not answering the problems.

Mr. KARTH. Mr. Pettis?

Mr. PETTIS. No questions.

Mr. KARTH. Dr. Pace, I hope that you understand the House is in session and there is legislation being considered on the floor and may well give cause to the absence of the many members. However, because it is important, we do have your testimony in the record and it will give those of us here an opportunity to ask questions. I wonder if you would care to proceed?

Dr. PACE. Thank you.

STATEMENT OF NELLO PACE, PH. D., PROFESSOR OF PHYSIOLOGY AND DIRECTOR, WHITE MOUNTAIN RESEARCH STATION, UNIVERSITY OF CALIFORNIA, BERKELEY

Dr. PACE. Mr. Chairman and members of the subcommittee, it is my privilege today to discuss with you the directions of the future for the NASA programs in the life sciences.

I am really going to address myself to a slightly different aspect of the biological sciences flight program; namely, the aspect referred to this morning by Dr. Adey as the contribution to terrestrial biology and medicine that would accrue from this kind of activity rather than pursuing the extrapolation to the manned space flight program.

I do this as an environmental physiologist with a career history of more than three decades spent in helping illuminate some of the dynamic adaptations which the human body can make in response to changes in the physical environment experienceable by man.

The thesis I should like to support is that the spectacularly successful development of the technology of space flight by the United States to date has made available for the first time a unique tool of major importance in advancing our understanding of the fundamental physiological characteristics of human being, and indeed of living organisms generally on the surface of the earth.

The appropriate application of this powerful new tool for life sciences research will not only enhance basic physiological knowledge, but inevitably it will lead to more rational planning for long-duration manned space flights on the one hand, and on the other hand to more rapid solution of some categories of clinical medical problems here on earth.

I ask your indulgence in permitting me to dwell for a moment on the role played by physiology as one of the fundamental biological sciences in attaining the immensely practical and directly personal objective of clinical medicine; to wit, the maintenance of or restoration of health of every living human being.

Physiology has sometimes been termed somewhat poetically "the handmaiden of medicine." While this description has a pleasant lilt to it, I much prefer the analogy that physiology is akin to the submerged bulk of the iceberg. The ofttimes near-miraculous accomplishments of the physician in saving human life or reversing the ravages of chronic disease are based directly and solidly on fundamental physiological knowledge. This is recognized in one of the six award categories of the Nobel prizes—that in physiology and medicine.

The task of the physiologist is first to identify all of the dynamic processes, both chemical and physical, which occur continuously in the living body, and then to understand their cause-and-effect relationships so that when a change is made in one of these processes the effect on the organism as a whole can be accounted for. Thus, the physiologist seeks understanding of life processes from the atomic and molecular level to the whole organism level in order to achieve a completely integrated, mechanistic explanation for the total functioning of the body.

It is clear that the more complete our understanding of human physiology, the more successful will be the physician in correcting or preventing the many physiological defects which plague man.

I might add, parenthetically, including those that might occur in weightlessness.

Let me proceed now to the subject of discussion for this occasion: How can the Congress, through it appropriations to NASA, achieve the most effective utilization of the formidable technology of space flight to advance biomedical science?

Brief reflection indicates that in learning how to overcome and effectively neutralize earth's gravity, the aerospace engineer has granted the biologist a uniquely important means whereby he can examine the precise role of this pervasive environmental force in shaping the structural and functional characteristics of living organisms over the millennia during which terrestrial evolution has proceeded.

Newton's universal law of gravitation tells us that an object with the mass and size of the earth will exert a constant attraction on other objects, like apples, at its surface. Furthermore, the magnitude of this attraction has a particular value that is characteristic of the mass of the earth, and causes any unsupported object to fall toward the earth's surface with constantly increasing velocity. This acceleration caused by earth's gravity is the well-known value of 980 centimeters per second or 32 feet per second per second, and is frequently referred to as 1 g.

While objects of any mass tend to be accelerated to the same degree by the earth's gravitational attraction, the force exerted on these objects when the rest on the earth's surface is given by the mass of the object multiplied by the acceleration of gravity. This force is what we recognize as the weight of the object.

It has been possible for a number of years to increase the weight of objects on the earth's surface by subjecting them to the added acceleration produced in a centrifuge, and important fundamental biological information is being obtained by studying living organisms in this fashion.

It has also been possible to alter the direction in which gravity normally acts on living organisms by rotating them continuously in clinostats as in the case of plants, or by keeping human subjects continuously in the horizontal position as in chronic bed-rest studies. While such studies again have yielded valuable results, they still leave unresolved the question of the effects of true weightlessness as produced uniquely in the long-term, continuous free fall which can only be achieved through space flight.

Thus if we are to understand completely the part played by earth's gravity in determining the particular characteristics of earth organisms, it is essential to use the orbiting spacecraft as a life sciences laboratory to study the effects of removal of gravity.

Let us consider briefly some of the evidence that gravity is a substantial and significant shaping factor in man's physiological adventures on earth. It is classical knowledge that man, in common with all higher animals, has evolved with elaborate sense organs to orient him with respect to position in space. These include the visual clues provided by sight and the inertial transducers of the inner ear, the semicircular canals.

There is in addition, however, a large array of sensors in the skin, the musculature, the skeletal joints, and other body subdivisions, known as proprioceptors, which continuously detect the pressures and stretch produced differentially in the various parts of the body by the action of gravity. Also, another part of the inner ear, the utricle, senses gravity. Thus, there is a large, continuous inflow of nerve impulses to the brain from the proprioceptors and vestibular apparatus of the ear which play a major role in the maintenance of posture, equilibrium, and orientation.

Besides these sensitive and rapidly responding gravity sensors, the body comprises other gravity-responsive mechanisms. It is a remarkable and very poorly understood physiological characteristic of man that the cardiovascular system can respond quickly and effectively to the large changes in hydrostatic pressure which accompany the daily shifts between the recumbent and erect positions of the body. The adjustments necessary to maintain the appropriate flow of blood to all the body tissues are exceedingly complex and include such changes as in the degree of constriction of the blood vessels, the distribution of the extravascular fluids, and the secretion rate of various hormones by the endocrine system.

While it is of great fundamental interest to the physiologist to understand how this intricate and delicately balanced set of cardiovascular adjustments is made, there is also a major practical medical problem at stake. One of the serious and usually ultimately fatal consequences

of congestive heart failure is the loss of the ability of the circulatory system to respond to the demands placed on it by gravity. Excess fluid tends to accumulate in the air spaces of the lungs, in effect producing drowning. Also, when such patients are in an upright position fluid tends to accumulate in the tissues of the lower part of the body. If the gravity-potentiated cardiovascular adjustments could be better understood, the management and treatment of chronic heart disease would be vastly improved. The solution of this problem alone would easily justify the cost of the entire space program to date.

Another major part of the body that is responsive to gravity is the weight-bearing system.

Mr. KARTH. May I interrupt?

Dr. PACE. Yes, sir.

Mr. KARTH. Your previous statement is very intriguing. I would assume you would agree, however, we could get answers to those questions at a substantially lesser cost than what we spent on the total space program, the way we have gone about it?

Dr. PACE. Sir, the point here is that one of the few ways in which the organisms can be——

Mr. KARTH. I agree with your conclusion.

Dr. PACE. Yes, sir—but, the general way in which attempts are made by physiologists to understand the regulatory mechanisms is to alter the environmental factor that is involved in the adaptive mechanisms under study.

Now, the only way in which we can reduce gravity is through space flight. And since we are dealing with the mechanism that is responsive to gravity, the opportunity for using orbital spacecraft to carry out studies of the functioning of the circulation represents a unique tool that permits us to study the effect of changing graviy in the direction of reducing it or eliminating it altogether.

There is no other way that I know of——

Mr. KARTH. I understand your point.

Dr. PACE (continuing). That the process can be studied.

Mr. KARTH. It is very intriguing. If we had given greater attention to the experimentation, to the biological process, and so forth, on a few flights, rather than very little attention on many flights, even though during that period of time we accumulated information, my point is we could acquire this information much more cheaply.

Dr. PACE. I'm sorry, I misunderstood your statement. Yes, sir.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. This particularly fascinated me, that since the beginning of time man's structure has been oriented to gravity, and you take him up and put him in a weightless state for a period of time, and still the heart functions as if it made no difference.

Mr. KARTH. You don't agree with that statement, do you?

Dr. PACE. This is the point I'm afraid we are not very clear on, that it makes no difference, sir.

Mr. DOWNING. I believe that was too general a statement.

Dr. PACE. I believe this is the answer we would like to have.

Mr. DOWNING. Maybe that is too general a statement, but we have had testimony here to that effect, as I recall, Mr. Chairman, that the heart performed its function without noticeable——

Dr. PACE. I would venture this statement, that gravity would be unique among all the environmental factors that physiologists have ever studied if altering the value produced no physiological effect. I think this would be one of the most remarkable findings in the history of biology.

Mr. DOWNING. I would think so, too, and yet you have so much against you.

Mr. KARTH. You have not yet so found out, have you?

Dr. PACE. We have had very little opportunity to determine whether this is the case or not, other than the fact so far that we have been able to fly men for periods up to 14 days, and in the case of the Russians to fly two dogs for a period of 22 days, and they survived. There has been very little opportunity to examine the physiological adjustments, responses, and changes, that accompany this exposure to the reduced gravity.

Mr. DOWNING. We had Dr. Christiaan Barnard of South Africa before this committee a few months ago, who was very interested in this field.

Mr. PETTIS. Mr. Chairman, may I ask the question I asked yesterday? In the area of near space, do you have any evidence that there is any deleterious effect upon human beings after you leave the earth and between earth and, say, 50,000 feet?

Dr. PACE. Yes, sir. This is one of the great areas of environmental physiology, and one of my favorite areas of study. Certainly the reduction in the pressure of the atmosphere and the accompanying reduction in partial pressure of oxygen causes profound effects that have permitted the physiologist to explore mechanisms relating to the regulation of respiration, and the functioning of the cardiovascular system. This is an example of another environmental factor, in this case the reduction in the pressure of the atmosphere and the corresponding reduction in the quantity of oxygen, that certainly produces profound physiological problems.

Mr. PETTIS. You say physiologically it is not as good for you to fly as it is not to fly?

Dr. PACE. No, by virtue of discovering the effects of reducing the oxygen pressure the physiologist was able to say to the engineer that he must maintain the sea level or near sea level partial pressure of oxygen. This led to the development of the pressurized cabin airplane that we all fly in when we take a trip in the modern jet aircraft.

But this was dependent on a study of the effects of reducing the atmospheric pressure, understanding that it was the reduction in pressure of the oxygen specifically, which in turn suggested a practical technological solution that now is in everyday use.

Mr. PETTIS. There is no greater incidence of cardiovascular disease or heart attacks among pilots, for example, than a traveling salesman driving around in an automobile?

Dr. PACE. No, sir, not as far as I know. In fact, because pilots represent a highly selected population as I'm sure you are well aware, I would venture to guess that the incidence among pilots is far lower than among the typical population of businessmen.

Mr. KARTH. What is the pressurization of the modern jets, 5,000 feet?

Dr. PACE. I think it goes up from 5,000 to about 8,000 feet, depending on the altitude at which the aircraft is flying.

Mr. KARTH. At any rate, when you are flying at 35,000, my point is you are not really suffering from the effects of 35,000 feet, you are really at 5,000 to 8,000.

Dr. PACE. Yes. This would be analogous to the provision of artificial gravity, let us say, to offset the reduction in gravity associated with orbital flight.

Mr. DOWNING. One last question.

Doctor, you say that changes occur in a weightless state, in the heart. What specific changes do occur that you are aware of?

Dr. PACE. This, I am sure, Dr. Meehan is going to give some very specific answers to. In general, it is clear that there is a redistribution of the blood in the body, such that the blood tends to gather in the chest, and this in turn leads to a number of complex sequences, the nature of which we do not understand altogether at the present time. But Dr. Meehan, I'm sure, will give some specifics on this point.

Mr. KARTH. Proceed.

Dr. PACE. Thank you.

I started to talk about the second major part of the body that is responsive to gravity: This includes the skeleton and the musculature, and represents more than half of the body's bulk. The musculoskeletal scaffolding is far from inert, and is well known to respond dynamically to the degree of loading imposed on it.

For example, the musculature can be caused to increase substantially in amount by a systematic program of weightlifting. Conversely, it is common experience that the musculature of a fractured limb undergoes considerable disuse atrophy as a consequence of the immobilization produced by application of a plaster cast. In analogous fashion, it has been demonstrated that the bones of the skeleton lose mineral content during prolonged bed rest, and conversely it is common clinical practice to encourage the orthopedic patient to put a weight load on a healing fractured bone to increase the compactness and strength of the healed bone.

The opportunity to study the dynamic metabolic process of bone demineralization and muscle atrophy by rigorous physiological research techniques during the chronic weightlessness of space flight would add immeasurably to our understanding of these phenomena, and could reasonably be expected to accelerate the solution of such diverse and important clinical problems as senile osteomalacia and muscular dystrophy.

There are numerous other examples of the influence of gravity on normal physiological processes. For instance, the basal metabolic energy requirement undoubtedly is higher under the 1 g. condition at the earth's surface than it is under the 0 g. condition of weightlessness. Study of the status of the thyroid gland during weightlessness could yield fruitful information concerning its normal regulatory function in connection with the basal metabolic rate.

Perhaps one of the potentially most important areas of fundamental biological interest is the role that gravity may play in the early development of the mammalian embryo. It appears that the first few cell divisions from the fertilized ovum may be dependent on a particular orientation with respect to gravity for normal tissue differentiation. Thus, the study of the development and growth of the mammalian embryo and fetus under conditions of weightlessness could provide substantial basic biological information.

Getting away from the animal world, another fundamental biological phenomenon with considerable practical importance is the process of lignification, or wood formation. It is evident that the evolution of the tall woody plants of the world, the trees and shrubs, had to involve the development of a mechanism to withstand the force of gravity in terms of simple structural strength. A study of lignification in plants growing in the weightless state could yield better understanding of this ubiquitous and valuable process of wood production.

To recapitulate, then, it is evident that the weightlessness of space flight can provide a powerful and unique tool for enhancing our knowledge of fundamental biological processes occurring in earth organisms, and thereby increasing the prospect of solving a variety of practical earth problems.

Now what about the implications of the physiological changes which occur during exposure to weightlessness for the manned space flight program? It is clear from the experience gained so far in both the United States and Russian flight programs that man can tolerate at least 14 days of weightlessness and that dogs can withstand 22 days of weightlessness. It is also clear, however, that a variety of physiological changes occur as a result of such experiences. There is evidence for the loss of bone mineral, for alteration in fluid balance, for deconditioning of the cardiovascular system, for alteration in endocrine function, and for change in central nervous system function. The data that exist today, however, are rudimentary at best. Certainly the biomedical personnel associated with the highly successful manned space flight program richly deserve the plaudits they have received for their important work. Indeed, one of the more remarkable aspects of their herculean efforts is that as much quantitative physiological data as we now have could have been obtained under the severe operational constraints involved in the manned flights.

On the other hand, it is difficult to define with certainty the physiological cost of protracted exposure to weightlessness. Furthermore, it is by no means evident that full adaptation to the weightless state has occurred in the length of the flights to date, or indeed would ever occur.

It would appear, therefore, that there exists a clear mandate for establishing a vigorous life sciences research flight program on at least two counts. First, if we are to have a full understanding of how the special physical environment of the earth influences the character of the life process, the role of earth gravity as one of the major environmental components must be examined critically. Second, if we wish to put man's forays into space for long periods of time on a solid, known basis we need far more extensive information than we now have concerning his physiological status in weightlessness.

I believe that an adequately broad life sciences research flight program should comprise at least three major elements. It should provide for biological experiment opportunities on both recoverable and nonrecoverable unmanned biosatellite-type spacecraft systems. These could or could not be man-tended as the individual experiment requirements dictate. Provisions should also be made for onboard centrifuges to provide essential in-flight control conditions.

A second element in a realistic life sciences research flight program should be the provision of ad hoc manned biomedical research spacecraft for the conduct of properly structured scientific experiments of human subjects and experimental plants and animals.

The third component of such a program should be the early identification and effective utilization of space available for appropriate biomedical experiments aboard operational manned flights currently being developed and projected for the future.

It is, I believe, self-evident that a life sciences research flight program should also include a substantial and soundly conceived correlated ground-based supporting research effort. For example, particular attention should be paid to the complement of weightlessness; namely, a careful and extensive examination of the effects of chronic exposure to accelerations greater than 1 g.

It should be pointed out that there is at least one other area of fundamental biology which can be advanced significantly through the provision of adequate space flight opportunities. This is the study of the many basic physiological functions of living organisms which exhibit rhythmic fluctuations of about 24 hours. The nature of these circadian rhythms or biological clocks is poorly understood at present, and their possible relationship to the cyclic geophysical events associated with the 24-hour rotation period of the earth can only be explored satisfactorily by spacecraft flights beyond the region of geophysical influence.

In sum, we can see that the technology of space flight now permits the study in a unique manner of the biological role of two very fundamental characteristics of the earth's environment: gravity, and the periodicities engendered by the earth's rotation. Neither of these factors can be studied satisfactorily by means of experiments conducted solely on the earth's surface. Both require the removal from the earth's surface made possible by space flight for their evaluation as biological factors.

Furthermore, the nature of the physiological measurements to be made, the requisite rigorously controlled conditions for many observations, and the particular biological phenomenon to be illuminated all dictate that experimental biological materials other than man, as well as man himsef, be used as test objects.

For example, a number of fundamental measurements of cardiovascular function or of central nervous system function require the surgical implantation of instrumentation deep in the brain or in the immediate vicinity of the heart. Other important experiments involve the permanent, selective interruption of nerve supplies to various organs, or the removal of portions of the endocrine systems. None of these common laboratory procedures of the physiologist lends itself to application in human subjects, and are always carried out in laboratory animals such as monkeys or rats.

In other instances it is essential to carry out a strict accounting of all food materials ingested and all materials excreted from the body in order to define the metabolic balance of an organism. In order to obtain meaningful results it is essential that this accounting go on for several weeks before and several weeks after a particular experimental condition, such as exposure to a period of weightlessness. The realization of a precise accounting of the metabolic balance in man

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is arduous even in a carefully regulated hospital ward, and the prospect for a suitably precise accounting under the demanding operational conditions of manned space flight is unrealistic, particularly when the requirement is understood to include periods of several weeks preflight and postflight. The use of suitable experimental animals greatly facilitates and improves this kind of experiment.

In still other kinds of experiments it is necessary to examine the effect of a particular factor, such as weightlessness, on successive generations of individuals. In these instances it is obviously most practical to use experimental organisms with short generation times.

Finally, there is a category of biological experiment which involves the interaction of two environmental factors, such as weightlessness and radiation, or weightlessness and low temperature for example, which can yield results of fundamental importance but which also involves the death of the experimental organisms to reach the necessary conclusions.

It is evident, therefore, that a substantial expansion of biomedical knowledge can accrue from the vigorous pursuit by NASA of a life sciences research flight program which would provide the means for carrying out numerous sophisticated biological experiments on a wide variety of living organisms, including man himself where appropriate.

Despite the risk of making such comparisons, I feel quite strongly that utilization of the potential of space flight for making significant advances in the area of fundamental biology has lagged far behind its utilization to advance other areas of human knowledge. A retrospective look at this exciting first decade of the space age brings the realization that the basic physical sciences have made enormous strides through the many flight experiments that have been carried out. In addition, the engineering technology of space flight which has culminated in establishing a series of operational manned lunar landings is a near-incredible achievement. An unmanned instrumented spacecraft is under active development for a landing on Mars in 1973. Active design is underway for the beginnings of earth-orbiting manned space stations.

Yet in this dramatic decade only two biosatellites have flown successfully, together with a minuscule number of small biological payloads on other flights. Despite the fact that a substantial data return was received from both biosatellite flights, and despite the fact that weightlessness has been shown to produce substantial physiological change at the cell level, as well as at the whole organism level, the space biology flight program is currently without visible means of support.

I should like to plead as an environmental physiologist that the opportunity for using space flight as a research tool of unique and fundamental importance be made available to the biologists of this country.

That is the end of my statement, Mr. Chairman.

Mr. KARTH. Thank you very much, Dr. Pace.

Mr. MOSHER. No questions at this time, Mr. Chairman.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. I think the testimony I have just heard from you has been fascinating, Dr. Pace. I wish I could have heard more of it.

Tell me, in your opinion—I don't know how to put this—is gravity necessary for life function?

Dr. PACE. I think this represents a fundamental and extremely important question. I am sure that I do not know the answer to it. I'm sure there are many biologists who would like to know the answer to it.

Mr. KARTH. In answer to Mr. Downing's question, what do you think? What is your expert judgment, Dr. Pace, not knowing obviously what the results are going to be?

Dr. PACE. I spent a number of years, really trying to arrive at an answer that I would find satisfactory for myself, Mr. Chairman, and I quite honestly can say I don't know. At this point in time I have very mixed feelings, based on the best judgment that I can exercise on what I understand about biological processes. It is a completely unresolved question in my mind. I'm not prepared to say unequivocally, man can adapt to weightlessness in the true adaptive sense of being able to survive indefinitely. I'm not prepared to say he cannot.

I believe the simple and clear answer is that we must have more information in the way of hard, objective, physiological observations before we can extrapolate to that point.

Mr. KARTH. I wondered if you had a feeling about the matter.

Dr. PACE. No, sir.

Mr. KARTH. That is very unfortunate.

Anyone else at the witness table have some kind of an intuitive feeling about that?

Dr. Adey?

Dr. ADEY. Sir, I think that at the level of living matter below the cellular level, as in dealing with virus particles, and so on, probably gravity is not a factor. But it is conceivably a factor in any organisms that are cellular, and particularly organisms that grow into multicellular aggregates. It seems highly unlikely these aggregates have grown without any effect of gravity being exercised on their evolution.

Mr. KARTH. Dr. Meehan?

Dr. MEEHAN. I would concur, and I think if you are pointing the question particularly at the human organism, you must realize he is probably one of the more highly adapted organisms that inhabit this earth.

Mr. KARTH. We hope he is the most highly developed organism.

Dr. MEEHAN. This has a corollary though, and that is the system gets very complex, and it therefore becomes difficult to alter his environment very much and still have it compatible with its existence.

Dr. PACE. After having a few seconds to think further, may I make one comment? Perhaps the finding to date that has me most uneasy in terms of this question of the long-term effects of weightlessness, have been the results from Biosatellite II that there are some rather drastic effects at the cell level. There is disruption of the chromosome structure of cells, and the longer this kind of process might go on, the more serious might become the cumulative effects in time.

This is purely intuition and based totally on other people's work, but this one finding has perhaps given me more pause than any of the others as a long-term explicit kind of potential failure point.

Mr. KARTH. Off-hand, Dr. Pace, can you think of any life function that is dependent on gravity?

Dr. PACE. Well, certainly our body conformation, as we know it, is clearly dependent on gravity.

Mr. DOWNING. When the good Lord made us, he intended us to walk on all fours, and the biggest mistake we made was to stand up, isn't that right?

Mr. KARTH. Speak for yourself. [Laughter.]

Mr. DOWNING. I am glad we stood up, but the skeletal and muscular structure of the body is better designed to walk on fours than it is on two, is it, or is it not?

Dr. PACE. We seem to have survived pretty well as a result of having reached the stage in evolution where we stood up on our two feet, so it is kind of a hard question to answer. My guess would be that it we take sheer success as a species on the surface of the earth, this had to be an improvement.

Mr. DOWNING. When our bodies were made, things like the pelvic cup were designed to keep the organs from sliding out on the ground because of gravity, I suppose; so it would seem to me that gravity would have some significant relationship to life functions, but we don't know what it is.

Dr. PACE. I quite agree, and I think furthermore it is particularly important to understand precisely the role of gravity, the particular value of gravity we have on the earth's surface. It is a very explicit number. It is one point. It is 980 centimeters per second per second acceleration. It is not 920; it is not 1,500; it is not 30. We really must know what that particular force field does in terms of the biological systems that exist on the earth's surface.

Mr. DOWNING. I quite agree.

Dr. PACE. The ability to vary this explicit value in a systematic way now provides an enormous tool to help us understand what role gravity plays in the total spectrum of biological phenomena we recognize as life on the earth's surface. It is a constant factor in the environment in which life has evolved and as biologists, I think it is mandatory we understand what role this has played in determining the characteristics of the life process.

Mr. DOWNING. Is there any differences in the pressure force of the heart in space, as opposed to on the ground?

Dr. PACE. Yes, sir; there are adjustments that go on simply because the pressure force for the return of the blood to the heart, as Dr. Meehan has discovered, changes in weightlessness. Certainly this leads to alterations in the way in which the circulatory system functions.

The circulatory system is a marvelous device, because what it does is to adjust to permit the pumping of the blood out the other side of the heart to go on serving the body needs for distribution of the materials carried by the blood; but how far this process of adjustment can go with long-term exposure to weightlessness, is one of the open questions at the present time.

Mr. DOWNING. I believe Dr. Barnhard brought up the possibility that you wouldn't have a heart attack in a weightless condition, am I correct in that?

Mr. KARTH. I don't remember that, but the record may prove you to be right. Incidentally, we did have some discussion this morning on the return to gravitation forces after having been under weightless conditions for some time, and the adverse effects that can have upon the heart. I have forgotten the terminology that was used. It wasn't heart attack.

Dr. MEEHAN. Syncope is the acute phenomenon and cardiovascular deconditioning is the process that goes on.

Mr. KARTH. The result is a fatal heart attack, Tom. You die.

Dr. MEEHAN. I would hate like heck to see in the newspapers tomorrow morning that I said you would get a heart attack flying in the spaceship. [Laughter.]

I know the gentlemen of the press too well. [Laughter.]

Mr. DOWNING. In returning from space, we have seen that some of the astronauts apparently have a loss of equilibrium as they get out of the capsule. Can you explain that?

Dr. ADEY. Sir, the explanation one offers is in the absence of actual observation as to the cause. But it is likely that the inner ear mechanism, which has a very delicate system of tubes with fluid in them, is very much altered by being weightless. Therefore, when one first becomes weightless and when one is reexposed to gravity, at both times, there will be alterations in pressure and alterations in movement of fluid inside this system.

Under those conditions, it is very much like being on a carousel and experiencing giddiness to the point of nausea. That has been reported in the Apollo missions recently.

It was also reported much earlier in the one Russian three-man flight, where they flew a cosmonaut, an engineer, and a physician; and the severity of their symptoms on entering weightlessness was in proportion to the length of their experience.

The test pilot had very little. The engineer who had done quite a lot of flying had relatively little, but the physician was most upset and I had the opportunity to talk to him personally and he said it was most unpleasant.

We would assume that when the ear is once again exposed to gravity fields on coming back to earth, this process reverses itself and again there is a transient period of this equilibrium.

Dr. DOWNING. Couldn't it be just plain seasickness from being in the ocean bouncing around in the capsule for 2 or 3 hours?

Dr. ADEY. It could be, but motion on the sea surface would exaggerate a preexisting condition. They are predisposed presumably to motion sickness as the result of the weightless state.

Mr. KARTH. Will the gentleman yield?

Mr. DOWNING. Yes, I would.

Mr. KARTH. We were talking earlier about simulated gravity induced by virtue of the centrifuge method. Wouldn't that have a tendency of making you seasick, of causing this inner ear to be unbalanced, particularly if it went on for a long period of time?

Dr. ADEY. Yes, there is a set of conditions called Coriolis forces which act on any body, placed on the centrifuge, and they result in some quite interesting physical effects.

In the case of a man on a centrifuge, if the centrifuge has a short arm that is rotating relatively fast, than there is a difference between the acceleration at the top of the head and, say, at the level of the mouth. Under those conditions, it is possible to experience very uncomfortable sensations if the head is moved at right angles to the direction of motion on the centrifuge. This is one of the factors that has to be taken into account in a circular or rotating vehicle as envisaged as the basis for a space station. Unless the arm of that vehicle, or its diameter, is large, these Coriolis forces are going to be very unpleasant indeed.

Mr. KARTH. You anticipated my next question, Doctor. Go ahead. Very interesting.

Dr. ADEY. I have little to add, except that this phenomenon is well known to pilots who use the phenomenon of nodding the head, I understand, in the course of wide turns, in order to see if the aircraft is skidding away from its anticipated course. The phenomenon needs to be taken into account from the point of view of habilitability of any space station that is built with artificial g.

Mr. KARTH. How big does a spacecraft have to be before the effect of the centrifugal force has an adverse effect upon the physiology of the individual?

Mr. ADEY. May I defer to Dr. Meehan, because he operates the only man-rated centrifuge in the State of California, and has done so for many years.

Mr. KARTH. Dr. Meehan.

Dr. MEEHAN. A locational arm in excess of 25 feet, approximately, is required to obviate the vestibular effects, to give a very direct answer.

Mr. KARTH. Would you say that one more time for me?

Dr. MEEHAN. A rotating arm of 25 feet in radius, or a 50-foot diameter machine would be the least.

Mr. KARTH. What is the diameter of the 6- to 12-man orbiting space station proposed at this time or engineered to be? Does anybody know?

Mr. ADEY. I think it is about 22 feet, or the diameter of the Saturn IV-B.

Mr. DOWNING. One final question. Have you noticed any effect on the eyes due to weightlessness or tear ducts? Is it possible to cry in space?

Dr. ADEY. I am not aware of any evidence about that, sir. We have found, in the monkey, some interesting alterations in the eye movements. At least in the first 3 days of the monkey's flight, there were spontaneous or apparently spontaneous rhythmic movements of the eye which related to the vestibular movements and he reacted in a way that suggested he found that unpleasant.

Mr. DOWNING. Thank you very much, Mr. Chairman.

Mr. KARTH. Mr. Pettis.

Mr. PETTIS. No questions.

Mr. KARTH. Thank you very much, Dr. Pace. Don't leave, we might want to come back to you.

Dr. Meehan, we didn't mean to keep you waiting until 3:15 in the afternoon, but please proceed, sir.

STATEMENT OF DR. J. P. MEEHAN, CHAIRMAN, DEPARTMENT OF PHYSIOLOGY, SCHOOL OF MEDICINE, UNIVERSITY OF SOUTHERN CALIFORNIA

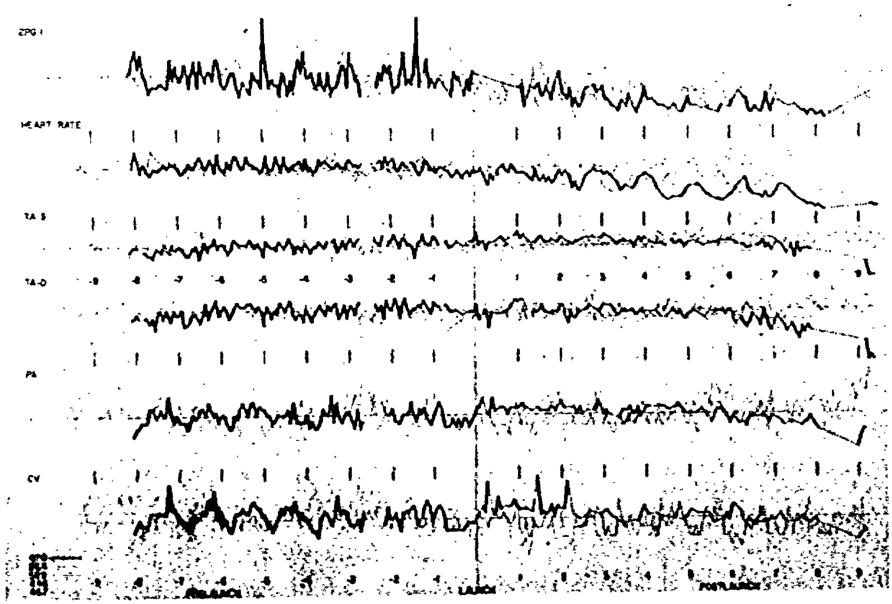
Dr. MEEHAN. I don't have a prepared statement for you, sir.

I would like to briefly describe the role that we played in the Biosatellite III program. I will show you some slides of the data and partially interpret them.

The information that was obtained in Biosatellite III, about the cardiovascular system, was an extension of the information that was obtained from the two-orbit flight of the chimpanzee Enos in Project Mercury.

The technological challenge of Biosatellite III was sharpened because of the smaller size of the animal. In addition, the instrumentation had to function to a high degree of reliability over a much longer period of time. We recorded the pressures within the cardiovascular system by means of placing small catheters or tubes at appropriate points within the vascular system and provided appropriate connections to pressure gages. The recording system was a straightforward hydraulic recording system. We also recorded the electrocardiogram and the respiratory rate by a single pair of electrodes placed on the lateral sides of the chest.

SLIDE NO. 1



Compiled cardiovascular data. The data is normalized over the prelaunch period such that data in the postlaunch period indicates deviations from the prelaunch data. Traces from top to bottom are as follows:

ZPG-1: Respiratory Rate.
Heart Rate.
TA-S: Systolic Arterial Pressure.
TA-D: Diastolic Arterial Pressure.
PA: Central Venous Pressure.
CV: Central Venous Pressure.

Dr. MEEHAN. I would like to show now a series of graphs that will summarize the data that we did obtain, and I would like to walk up to the charts, if I might. I feel a little more at ease if I do this.

I don't think we need the lights out. The upper record along here is the respiratory rate. Below that is the heart rate. The dark red line is the flight animal, and the fainter colored lines are the four additionanl animals that were prepared and held in part as controls at Cape Kennedy during the flight.

The data during the prelaunch period has been normalized so that after the launch time here it is rather easy to see if there has been any change in each of the various parameters.

The control animals were put through a simulated launch and then placed in a more strict degree of isolation so that the conditions of the animals on the ground could be simulated to be rather close to those of the animal in flight.

If we examine the respiratory rate, we will find that the flight animal experienced a decrease in respiratory rate as the flight proceeded. The control animals experienced a similar decrease in respiratory rate. The heart rate showed a marked decline as far as the flight animal was concerned, and here you can see the shift in circadian rhythm when it is compared to the cycles as can be seen on the ground animals. One of the ground animals showed actually a small increase in heart rate.

The two next lines down are the systolic and diastolic blood pressure and you find the systolic blood pressure held up quite well until past the seventh day, approaching the eighth day, as did the diastolic pressure. The control animals, as you see, maintained satisfactory pressures throughout.

Mr. KARTH. It was much more even though, Doctor?

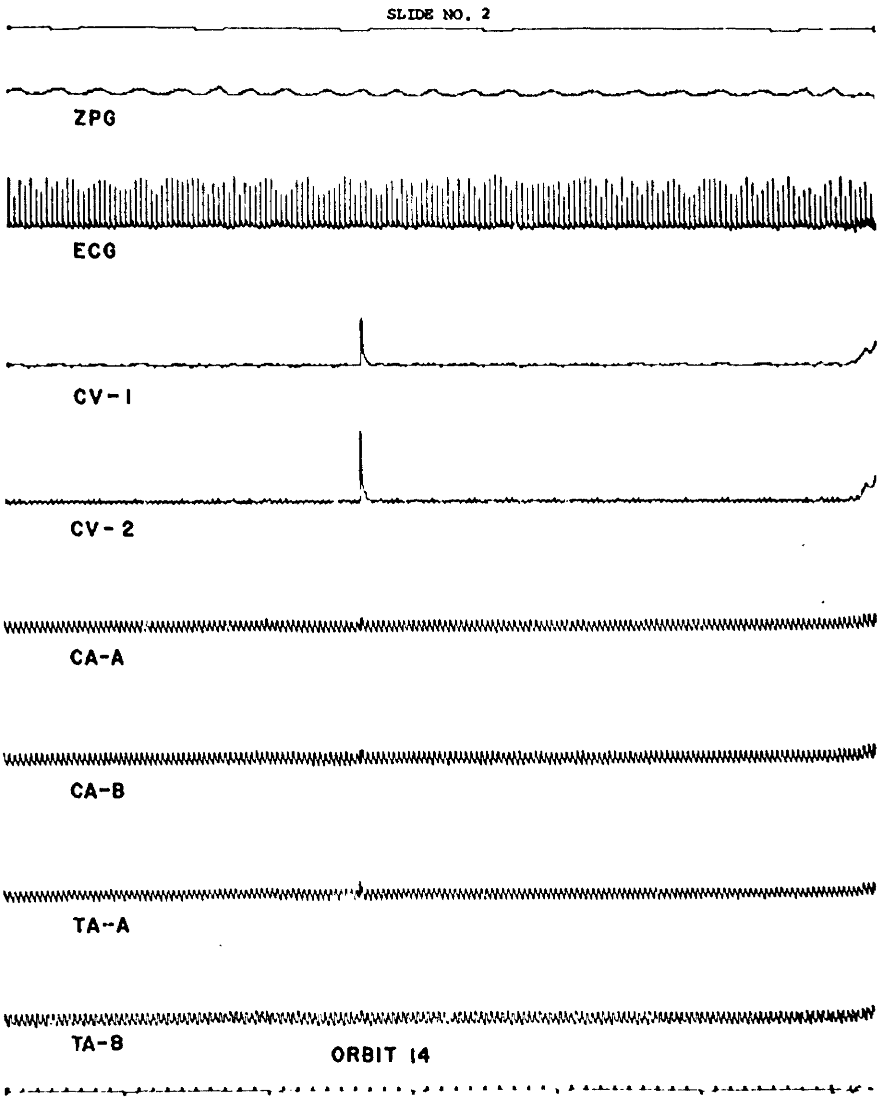
Dr. MEEHAN. Sir?

Mr. KARTH. It appears by your chart that the flight animal's systolic and diastolic blood pressure was much more uniform than the nonflight animals. Is that a fair assumption on my part, particularly on line 3? Is that the systolic?

Dr. MEEHAN. The animals on the ground were tilted in position twice a day from a head up to a horizontal position, and that occurred even on the control animals here. It did not occur in the animal in the flight, so any variation due to that change in position would disappear. The same is true with the diastolic pressure, although the effect wouldn't be quite as marked.

The bottom two graphs are the central venous pressures that were recorded. You see this cyclic change in central venous pressure that occurs each day. This is largely due to the change in position of the animal. When the animal enters weightlessness, of course, you lose that phenomenon, and we had two catheters getting the central venous pressure. One was backing up the other. As it worked out, our recording system functioned 100 percent perfectly, and we lost no data throughout the flight nor, as a matter of fact, did we lose any data on any of the ground animals. Our data record was a hundred percent.

If we can see the next slide quite briefly.



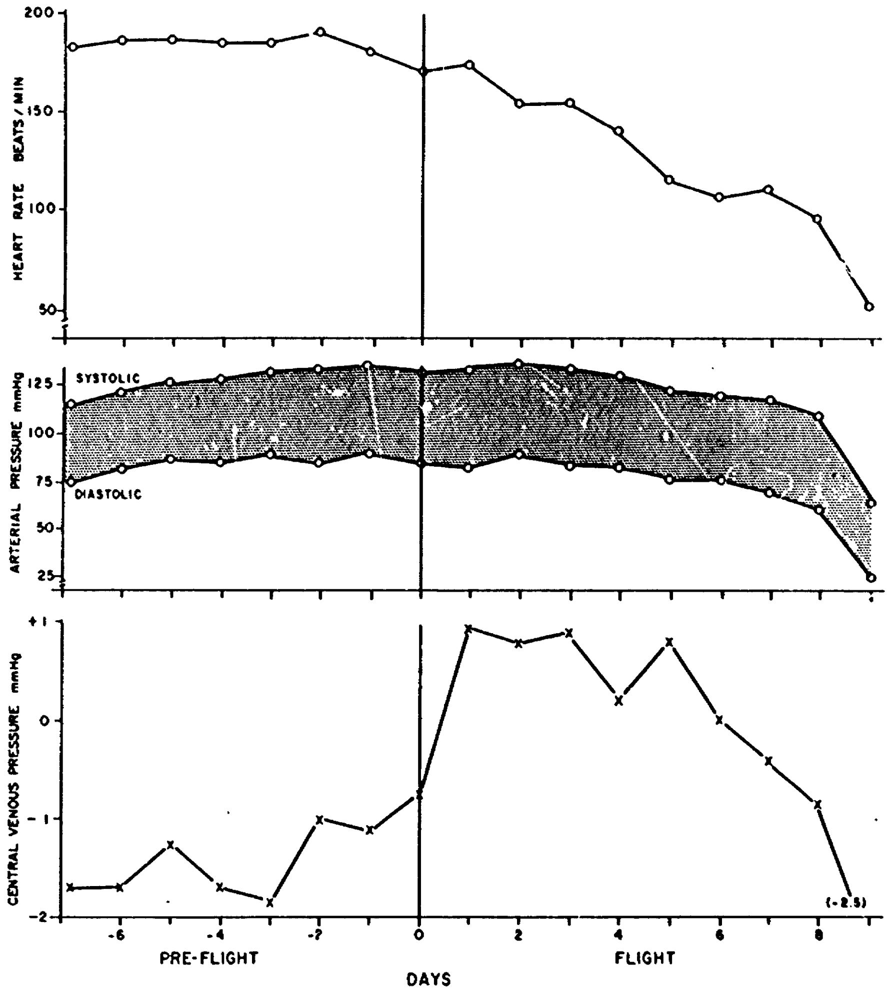
Sample of data received at Goddard Space Flight Center.

Orbit 14:

ZPG .... Respiration
ECG .... Electrocardiogram
CV-1 .... Central venous pressure
CV-2 .... Central venous pressure
CA-A .... Arterial pressure
CA-B .... Arterial pressure
TA-A .... Arterial pressure (backup system)
TA-B .... Arterial pressure (backup system)

Dr. MEEHAN. This is a sample of the received data at Goddard, the respiratory rate at the top, electrocardiogram, two venous pressure channels, and then the arterial pressure data.

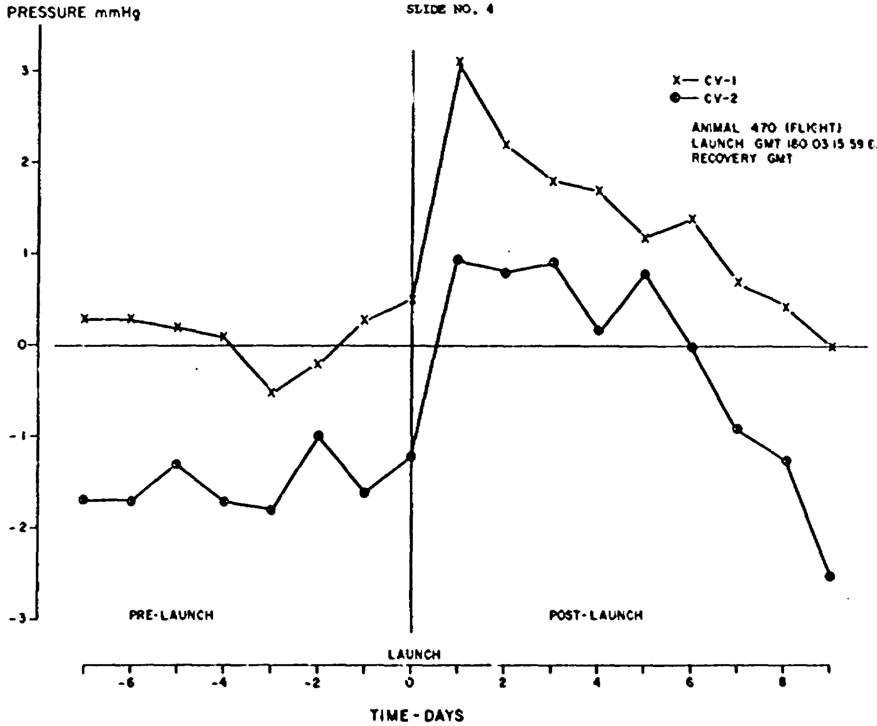
SLIDE NO. 3



Reduced cardiovascular data. Daily averages of heart rate, arterial pressure and central venous pressure.

Dr. Meehan. This slide summarizes the heart rate, the blood pressure, and central venous pressure. The points plotted are 24-hour averages for each day. The heart rate at the top, you see, starts to fall a bit even before the actual launch time. The animal is receiving a little less human attention then, and the heart rates does calm right down. You will notice, however, that the fallen heart rate does not particularly alter the blood pressure of the animal. The blood pressure there is maintained at adequate physiological levels right out to the beginning of the eighth day, and then it shows this marked decline.

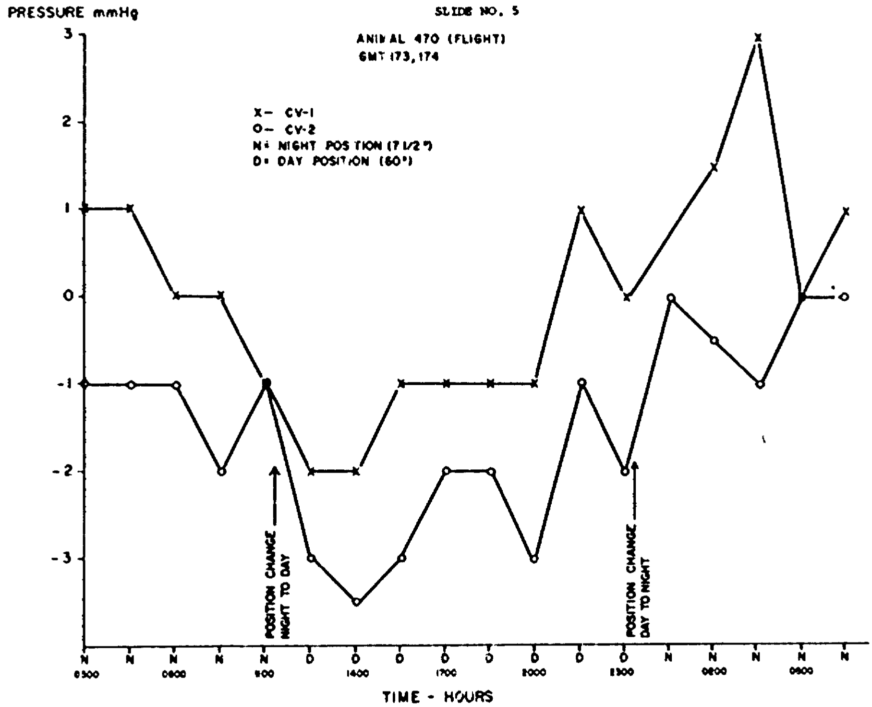
The central venous pressure, because of the change in position, is lower prior to launch. At launch, it goes up to higher values. It went up a little higher than originally expected as shown in the marked dip, and it stayed up above ground control values until about the seventh day, and then the two started to come down to levels approximately of the ground values.



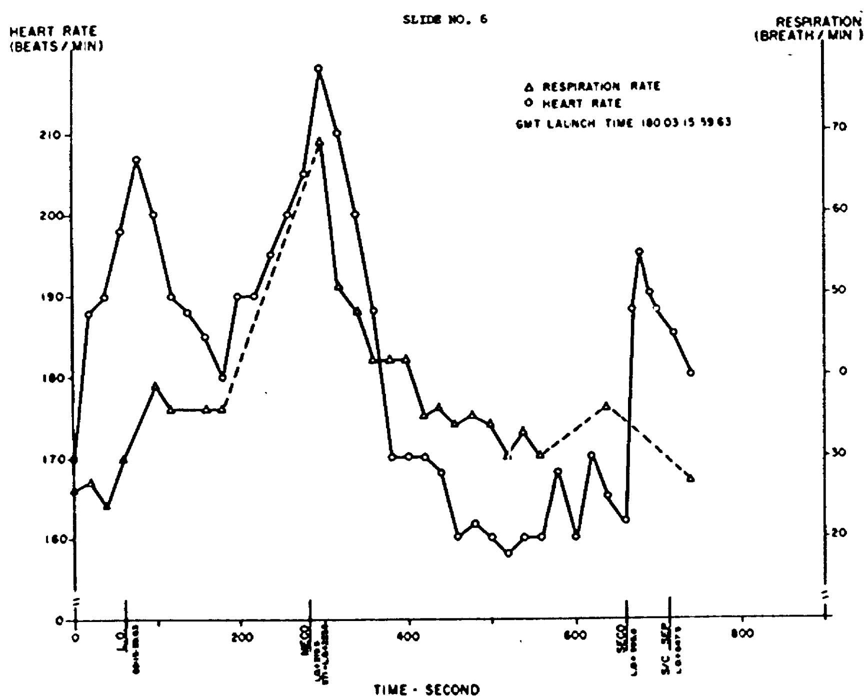
Central venous pressure data obtained from each venous catheter.

Dr. Meehan. This is the data from both of the catheters in the venous system. This graph is the one we saw. The second set of data comes from the catheter that was actually placed a little more peripherally. The changes that occur, the fact they have occurred in both catheters, and both measuring sites, gives some assurance to the actual accuracy of the data.

This shows, in larger scale, the effect of changing the position of the animal. The position changed here. The animal is placed in a daytime position, and the central venous pressure is going to fall; and at this point, he is changed to a nighttime position. That is, he is lying down and essentially the venous pressure is going to rise. This points that out.



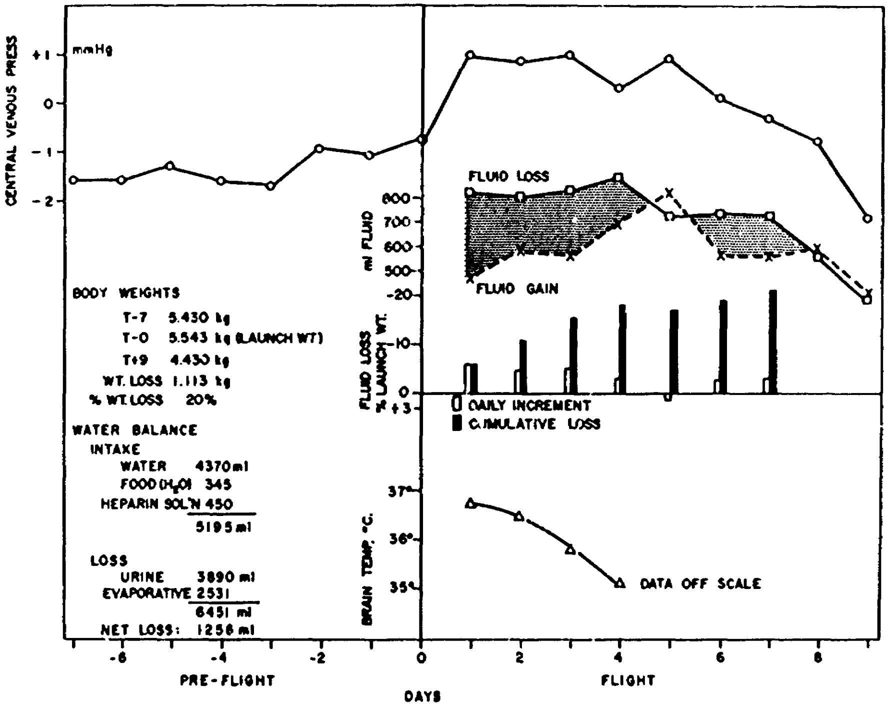
Central venous pressure data from each venous catheter through one 24-hour period. (Flight animal #470.)



Cardiac and respiratory rates during launch sequence.

Dr. MEEHAN. This is the respiratory and heart rate data during the liftoff sequence. Starting here at liftoff, main engine cut off, you will see the heart rate is a rather sensitive indicator when something is going on. It goes up and the booster ignites, the main engine cuts off. You see the heart rate reflects very nicely most of the mechanical events that are occurring in the launch cycle.

SLIDE NO. 7



Summary of fluid loss data plotted in relationship to central venous pressure.

Dr. MEEHAN. The next slide summarizes the venous pressure data and places alongside the fluid balance data as best we have it right at this moment. The central venous pressure change we have seen before. The graph here shows the fluid loss plotted along this line here. The fluid loss is the water that the animal has lost in his urine, and also by means of evaporation. That can be calculated over here. The fluid again represents the fluid consumed, the water that comes from the indigenous metabolism of the food he has eaten and also the anticoagulant solution that has been infused through the cardiovascular catheters.

The fluid again is going along here. The dramatic way to look at that is to examine the bar graph that we have here. The fluid loss is plotted as a percentage of initial launch weight and, as you progress along the bar graph here, the black part indicates the cumulative loss on day 1, day 2, day 3, day 4, and you see somewhere in the first 3 to 4 days of flight the biggest percentage of body weight has been lost.

There is some interesting further loss, but it is occurring at a much slower rate. This initial loss is undoubtedly due, you see, to the loss of fluid as is indicated by this graph up here.

The animal brain temperature did fall. I am not prepared to comment on that right now.

The important thing, I think, is the adjustment that occurred in this early part of the flight here. Presumably, that results from the shift in blood volume. The central venous pressure is a measure really of the amount of blood that is filling those vascular structures adjacent to the heart, and the venous pressure then is a measure really of the amount of blood that is available to the heart for it to carry out its normal function.

As it happens, the body has special stretch receptors located in the atria or special reservoir chambers of the heart that signal the body the extent of filling of these organs. If these organs are well filled with blood, the body enters into a series of adjustments whereby the total blood volume will be reduced, and this means that the body will excrete water, it will tend to reduce the red cell volume. It reduces the total amount of plasma protein that the body has. It enters into a fairly major metabolic adjustment.

Conversely, if the atria are underfilled, the body attempts to enter into a series of adjustments that will restore or enlarge the blood volume.

In the course of our everyday life, we change position with respect to gravity. We lie down when we sleep. Under those conditions, the body gets a signal that would say we should reduce our blood volumes and most of us can be aware of this if you lie down after a meal and are watching the television. In about an hour's time, most everyone will have the urge to go to the bathroom and urinate. This is a common experience. This is the first response of this mechanism operating to reduce central blood volume.

Conversely, if you stand up and are active, you are very apt to experience thirst and have a desire to drink fluid or to get more fluid.

In weightlessness, then, the individual is essentially in a lying down position all of the time. Blood shifts to the central vascular structures and the physiological signal then is that there is lots of blood available to the heart. The blood volume should be reduced. Then you have the processes, physiological processes, operating to accomplish this.

This, however, is carried out only on the basis of information or physiological information perceived right adjacent to the heart. It measures only the supply immediately behind the dams. The body has no information or sources of information physiologically as to how much blood is distributed elsewhere within the cardiovascular system.

So the main censors, the main devices that tell you how much blood is available, are located next to the heart. They are not capable of telling how much blood is distributed elsewhere within the vascular system, so that in the absence of gravity it is possible to reduce your blood volume quite significantly; but as far as the body is concerned physiologically, it still has enough blood and this is enough blood for the heart to function properly, and it will.

This finding in the original description of this mechanism was accomplished by physiologists interested in aerospace physiology or astrospace physiology at the time, and it has been thought it would supply a role in determining blood volume and cardiovasular performance in the weightless condition and, indeed, it has.

Mr. KARTH. Doctor, what happens or what is the result of this high volume of blood in the heart area, in the cavity area for prolonged periods of time? What effect would that have? Let's say it lasted for 2 months. What is the result?

Dr. MEEHAN. That I don't know. We would expect an adaptation to occur, but the speculations that you could make would be derived from looking at the behavior of animals that probably are not much affected by gravity. The easiest animal to look at would be something like a seal or a sea lion that lives in water and has most of its hydrostatic columns balanced out by that effect.

The striking thing that one sees in an animal of that sort is the tissues beyond the thorax are very dense and turgid and not very distensible whereas the issues beyond the thorax are rather sloppy and the veins that bring blood back to the heart are indeed very distensible and can accommodate a great deal of blood.

Mr. KARTH. So the effect would not be great. How about man?

Dr. MEEHAN. In man it is hard to speculate how the adaptation would occur. I think there is an indication from the manned spacecraft data I have seen thus far that the tone or the ability of the peripheral veins to contract becomes less so that the blood might distribute more peripherally. That is one thing that would help. The other thing that would help would be the adaptation on the part of the sensor mechanism that tends to reduce blood volume.

Mr. KARTH. What if it wouldn't redistribute? What happens then? That is my question. What happens if it just stays there?

Dr. MEEHAN. As long as there was no demand placed on the individual for redistribution of that blood volume, he would probably be all right. This was, if he was lying quiet or not doing much, no great deal.

Mr. KARTH. Then he doesn't drown in his own blood after a while?

Dr. MEEHAN. No. But, on the other hand, if he were asked to work the body temperature would go up. There will be increased bloodflow to the skin in order to achieve thermoregulation. Then you are calling upon the heart to deliver considerable blood volume to another part of the vascular system. The individual then does not have that available. This might be a problem observed thus far in astronauts doing extravehicular activities.

Mr. KARTH. What takes place? Blackout?

Dr. MEEHAN. The effect that would occur would be noticed cardioacceleration and then one of inability to work, weakness, difficulty in working. This would be the standard response that a person would notice if the cardiac output was not adequate to meet the workload.

Mr. KARTH. Could it even affect his ability to move around, agility or whatever the requirement might be?

Dr. MEEHAN. It could, yes. The human being is so very much adapted to dealing with this matter of the distensible venous system that we really confuse it when we put it in an environment where the volume regulating system is frustrated. It is one of the few situations in physiology where a physiological sensing mechanism is completely frustrated in terms of normal function.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. Thank you.

The astronauts when they engage in extravehicular activity seem to become exhausted so quickly. Is this because they have been used to utilizing gravity in their normal everyday life and now they are in a position where they have to compensate—I don't know what I want to say—without it, in other words? When you lift your foot up like this, you don't have to worry about it going down to the ground again, but if you were up there, you do.

Dr. MEEHAN. Yes.

Mr. KARTH. It takes energy to move in in both directions.

Dr. MEEHAN. Can I stand up for a minute.

Mr. KARTH. Is that why you get twice as tired in space?

Dr. MEEHAN. When you stand up in a position such as I am in right now [demonstrating] approximately 20 percent of my blood volume or a little more will shift from my thorax down to the tissues below the level of my pelvis. If I start to work and move these muscles, I will compress the vascular beds down there and reshift some of the blood back up toward the heart and make it available. That becomes a reserve store of blood that can be used.

I have that partly because of the gravitation loading that occurs in the venous system when I am standing around quietly. You take away this gravitation loading, then the blood volume tends to be reduced, and then I don't have that reserve to call upon if I need that volume of blood, say, in my skin to cool me off or in other muscles to maintain good nutrition of those muscles.

Mr. DOWNING. If you were standing in space, just as you are now, where would your blood volume be?

Dr. MEEHAN. Right around my heart. It would be just as though I am lying down. The other factor that occurs involves the movement of tissue fluid which is a little more subtle than the movement of blood volumes and this was very evident in the monkey and it has been true of the astronauts and cosmonauts, too.

When I am standing up, the pressure in my venous system is reflected down to the capillaries in my lower extremities. The capillaries are those vascular structures where tissue fluid exchange takes place between the blood and the tissue fluid that actually baths all of our living cells, and this is a very carefully balanced thing so that fluid can exchange back and forth across this membrane and we don't get too much tissue spaces and we keep just the right amount of fluid within the vascular system so things work.

If we stand erect and very still for a while, we can actually get the capillary pressure up so high we will lose fluid into our tissues and I am sure you know if you stand still erect for a while your shoes get tight and your feet swell. This is because you are moving fluid out into these tissues.

What happens dynamically is what happens when you are standing up. The pressures on the capillaries of the face and upper parts of the body drop such that it tends to mobilize fluid from the upper end of the body and transfer it down to the lower end of the body.

When you lie down, the opposite thing occurs. There is a correlation that I can tell you about this. In sleeping all night and in the horizontal position, fluid tends to redistribute more uniformly over your body and if you have got a beard like mine, you might get up, have a shave, and in half an hour you wish you could shave again. What

has happened is that some of the fluid in the skin of the face has been mobilized and transported to the lower part of my body, and it exposes those hairs a little more.

The opposite story that goes along with this is that if you are going out in the evening, you may shave, you see. Then you get a nice close shave and then if you get horizontal again too soon, the fluid will accumulate in the skin and obstruct the hair follicles. Then the hair, instead of coming out through the follicles and penetrating the skin, you get an ingrown hair. You can use that bit of information as you wish. [Laughter.]

Mr. KARTH. What is it we shouldn't do, Doctor? [Laughter.]

Dr. MEEHAN. This simply dramatizes the way in which the extracellular fluid can be mobilized into the cardiovascular system.

In the problem of clinical heart failure, you have a situation where the mechanism that senses the volume of blood within the vascular system has failed. It has adapted and it is no longer recognizing the fact there is really too much blood in it and what happens is that the pressure in the venous system gets too high and then you start accumulating tissue fluid.

Now, in weightlessness, the type of adaptation that could occur that would be useful would be were those receptors to adapt in a similar way so they wouldn't be quite so sensitive to the amount of blood in the thorax. The other thing that would be helpful would be in the venous system change it wouldn't shift blood back toward the heart quite so readily.

I don't know which of these factors may be operating in weightlessness. I know they both do. I can't predict as to what extent each will operate.

The important thing in considering these changes is that when you alter blood volume you are bringing into play very significant metabolic regulatory functions through the neuroendocrine system. We are asking the body in one case to make more blood, make more red cells, and in the next case we are asking the body to reduce these things, and the implications then involve a great deal more than simply just the management of blood volume.

Mr. KARTH. Doctor, I am not sure this question has anything to do with these hearings. I am of the mind that it doesn't. But knowing all that you people know about what is good and what is bad and how it affects you and how it doesn't, how come you guys don't live about 10 years longer than the rest of us?

Dr. PACE. How do you know we don't? [Laughter.]

Mr. KARTH. I don't think you do. I saw some statistics on that once. It seems to me that we probably shaded you by a year or so.

Dr. MEEHAN. These are other problems that involve other considerations.

I would like to make just a couple of further remarks that the techniques we have used for measuring blood pressures in both the chimpanzee and in the monkeys have been used for doing physiologic studies in people. I did catherize an Air Force pilot, Dr. Jim Roman, who flew an F-100 aircraft through a variety of maneuvers to validate the technique for making indirect blood pressure measurements in flight that he had developed.

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Presently we are doing some work with divers with catheters in the central venous system, again trying to study the dynamics of the fluid shifts that occur in that situation. So the techniques we have applied to the animals can and have been applied to people for collecting data. One can do this with a fair amount of safety, but only after you have done it in the animal subject and you have your goal clearly in mind and you know exactly what the hazards of such procedures are.

I think that this brings me to the statement now that good research on man in any unusual environment must be coupled to good research on the animal subject and you can readily take procedures carried out on the animal to man under advised conditions. You can use the insights and the data you obtain from your animal experiments to guide you in designing the more difficult and occasionally somewhat more risky human experiments.

I very firmly believe that any program that is going to put man in an unusual environment must be coupled with a logical and well-thought-out program using the experimental animal, and I think we have to be very, very careful in assessing those systems that we want to study and select our animal subjects so we will get the most useful information.

This would mean that the primate is very frequently the animal of choice, but on the other hand, this would not exclude by any means experiments carried out on even very small forms such as mice or rats. The experimental goals defined frequently can make excellent use of relatively small animals that can be launched and put in environments that are relatively inexpensive to prepare and maintain.

Thank you.

Mr. KARTH. Thank you very much, Dr. Meehan.

Are there questions? Mr. Symington.

Mr. SYMINGTON. One question.

Doctor, I don't know enough about primates to know, for example, whether the primate is fastidious with respect to his eliminations. I am not sure how that worked over a period of 8 days. That is not as important as my recollection of something we heard here before concerning the difficulty of astronauts and the rather peculiar manner in which they had to take care of themselves. In light of this discussion of the hydraulics of the man, if a man does not function regularly, that has something to do, doesn't it, with the water in his system? We were given to understand that some of them even took certain medication in order to forestall movement because of the bother it put them to, and yet this in itself might have been endangering their physical condition and possibly their ability to cope with stresses of one thing or another. Over a period of time it could only get worse.

Dr. MEEHAN. Any alteration one makes in a bodily function of this sort is an additional stress to the individual. And how he will handle it will become an individual matter.

Mr. KARTH. Would the gentleman yield?

Mr. SYMINGTON. Yes.

Mr. KARTH. Was Bonnie so prepared as to eliminate whatever stresses that might come about from not being as well situated, for example, as you might be here on earth with these eliminations?

Dr. ADEY. The bowel elimination problem was one on which a great deal of effort was spent over a period of almost 3 years by Ames Re-

search Center, by USC, and by UCLA. Finally a method was adopted in which the animal was seated on the couch with an orifice in it and a special container was attached for collection of the bowel waste. Our prime consideration was, indeed, the comfort of the animal and the system seemed to work reasonably well in the weightless state, even though the elimination from the animal was at times in a liquid condition. I think it is a very real truth that if you don't know how to manage the wastes in this sort of experiment then you don't have an experiment.

For the urine, Dr. A. T. K. Cockett, of the University of Rochester, at Los Angeles Harbor General Hospital developed a method of direct connection from the bladder of the animal through a tube to the urine collection device. At the end of the flight the capsule was as clean in the interior as at the time of launch. There was absolutely no sign of any waste contamination on the interior of the capsule. The animal itself had a small amount of bowel contamination on the lower part of its back, but that was all.

Mr. KARTH. Thank you.

Go ahead, Mr. Symington.

Mr. SYMINGTON. Well, of course, man is not going to be similarly equipped, and I don't know whether you are satisfied now with the mechanisms which are available to man in terms of the dangers that you perceived in extended weightlessness and the digestive process and its effects on the cardiovascular system, and so forth.

Are you satisfied that these astronauts are sufficiently comfortable in these processes so that this is not a factor even to consider?

Dr. MEEHAN. Considering the type of individual that an astronaut is, I should believe that this would not be a significant factor in his performance.

Mr. SYMINGTON. Has there been any change that you know of in the mechanics involved from, say, the Borman flight to the 28-day upcoming flight?

Dr. MEEHAN. No, sir; I am not familiar with the technology.

Mr. SYMINGTON. Mr. Chairman, this was an executive session where we took this testimony, so perhaps I would just not go into it any more, but I think we did get the impression it presented a problem both physically and psychologically.

Dr. MEEHAN. I am sure it would be a psychological problem, especially in an enclosed environment. It creates an unpleasant situation that most people would not readily accept, but those are general observations.

Mr. KARTH. Are there further questions?

Counsel, Mr. Hammill?

Mr. HAMMILL. I would like to ask one question.

Earlier, I think it was Dr. Adey who said that the instrumentation on the cosmonauts was more extensive than on our astronauts. I think you also said that they have done experiments with many more animals than we have. We had two successful biosatellite missions. Do you know the extent of the biosatellite program of the Soviet Union? How would you compare it with our own and how would you compare the biomedical aspects of their manned spaceflight program with our own?

Dr. ADEY. Well, sir, in the first place, the published data indicates that they have flown many spacecraft with living material for scien-

tific purposes. This includes one of the circumlunar flights with quite a zoo of small animals including a turtle.

The philosophy that has been stated in academician Parin as one of the leading Soviet people in the field is that they attach great significance to the animal data as a fund of information to be applied to all aspects of cosmic flight.

Now, in the manned area, their published data indicate that they have done a great deal of electrocardiography and phonocardiography. The phonocardiography records the heart sounds and allows them to relate aspects of the heart cycle to the movement of blood into the vessels of the periphery.

They have also published far more detailed information on the brain reactions in space than we have. They have published, for instance, data on four or five cosmonauts extending out to 4 and 5 days. This has been very interesting in terms of the gradual changes they report in the brain wave pattern with time.

At this juncture we don't have that sort of information about the brain from the U.S. manned program. I am speaking to the brain because that happens to be my specialty.

I believe that they have also recorded the eye movements in a number of their cosmonauts. We have no detailed information of that kind. They appear to have made many more estimates on blood and urine than has been at least reported in our own manned flight program.

Mr. KARTH. Dr. Adey, biologically speaking, have you learned more from the Russian manned flights than you learned from the U.S. manned flights?

Dr. ADEY. My answer should be "Yes." I think I have learned more from the continuity of data and the volume of data.

Mr. KARTH. Would that be true insofar as the other two witnesses are concerned?

Dr. PACE. I think for myself I would say that, in some areas, perhaps this is true. My feeling is that there is such a vast spectrum of biological information which we need it is a little hard to say at this time whether or not one area that the Russians happened to specialize in is more important.

Mr. KARTH. You should be more appreciative for what you get under those circumstances.

Dr. PACE. Yes.

Mr. KARTH. Totally, do you feel you have been able to get more biological information from the Russian manned spaceflights than from the U.S. manned spaceflights? Total. I am not talking about areas.

Dr. PACE. I would say we have gotten different kinds of information. I would hate to make a quantitative comparison because we don't know which are relatively more important.

Mr. KARTH. We have many more hours of manned flight. I don't know how many more times, but considerably more.

Dr. PACE. They have flown many, many more animals and it is a little difficult to equate these sources of information.

Mr. KARTH. I am referring to manned flight.

Dr. PACE. I am referring to the value for manned flights in terms of understanding the fundamental physiological changes that go on in weightlessness.

Mr. KARTH. How about you, Dr. Meehan?

Dr. MEEHAN. I will have to take a mid position. Some data they have been reporting has been more extensive in some areas. As far as I know, we have the only programs that have measured intravascular pressures. The Russians have done experiments in which they have produced cardiovascular parameters of an indirect nature that give a good deal of information about the cardiovascular system. They have been more diligent in that direction than we have.

Mr. HAMMILL. Have they held back any information or do you suspect they might have? Earlier you may recall the chairman mentioned the existence of a bilateral agreement between our two countries and specifically for the exchange of this kind of information, and I am just wondering how effective that agreement has proven to be.

Dr. ADEY. Sir, we have noticed in the flight of two dogs in the Cosmos 110, that they have produced the data in parcels. There was a release about a year ago which followed about a year after the initial release. On the basis of the two main sets of information that we now have, they may have more information.

Mr. HAMMILL. So there is a suspicion they are not quite living up to this agreement.

Dr. ADEY. It takes time to prepare the data for publication and they could be legitimately working on the data.

Dr. MEEHAN. I might say in the last personal contact I had with any of the Russian scientists the exchange was open and free. I had no feeling that I was being denied any information whatever.

Mr. KARTH. Are there further questions?

We have a rollcall vote on the floor. The House has been very generous to us for not having called upon us to go over there and answer the rollcall prior to this time.

Let me just say, Dr. Adey and Dr. Pace and Dr. Meehan, we are most grateful to you for your very valuable testimony. We are delighted you could come and be with us and I think greatly assist the Congress of the United States in making decisions for the future insofar as it relates to biological research. We are indebted.

Thank you very much.

(Whereupon, at 4 p.m., the subcommittee recessed, to reconvene at 10 a.m., Monday, November 17, 1969, in room 2325, Rayburn House Office Building, Washington, D.C.)

(Subsequent to the hearing, Dr. Meehan submitted a further statement as follows:)

A combination of observations on man along with appropriately designed studies on experimental animal subjects is the best, most rapid approach to the necessary understanding of the physiological adaptions that take place in the weightless environment. The complex instrumentation required for collecting fundamental physiologic data can only be applied to the primate subject. Less exacting measurements can be made on the human. Correlation of the two types of data then makes it possible to develop a reasonably accurate picture of the physiologic adaptions occuring in weightlessness.

Although the Bonny flight did not last as long as planned, the results are particularly meaningful and clearly indicate the necessity of further flight experiments.

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THE FUTURE OF THE BIOSCIENCE PROGRAM

MONDAY, NOVEMBER 17, 1969

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND ASTRONAUTICS,
SUBCOMMITTEE ON SPACE SCIENCE AND APPLICATIONS,
Washington, D.C.

The subcommittee met at 10:15 a.m., in room 2325, Rayburn House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. KARTH. The subcommittee will be in order.

We continue today the hearings that we started last week on the future of the bioscience program. Today we are honored to have with us two witnesses from NASA—Maj. Gen. James W. Humphreys, Jr., of the U.S. Air Force and Director of Space Medicine, Office of Manned Space Flight, and Dr. Charles A. Berry, Director of Medical Research and Operations, Manned Spacecraft Center, Houston. Following them will be a representative of the medical profession, Dr. James V. Warren, chairman of the department of medicine at Ohio State University, Columbus, Ohio. We are pleased also to have with us again Chairman George P. Miller of the full committee.

We will begin today by hearing from General Humphreys and Dr. Berry who will give a joint statement, as I understand it; is that correct?

General HUMPHREYS. That is correct.

Mr. KARTH. Who wishes to proceed as the representative of this joint venture?

General HUMPHREYS. I will.

STATEMENTS OF MAJ. GEN. J. W. HUMPHREYS, JR., USAF, MC DIRECTOR, SPACE MEDICINE, OFFICE OF MANNED SPACE FLIGHT, NASA; AND CHARLES A. BERRY, M.D., DIRECTOR, MEDICAL RESEARCH AND OPERATIONS, MANNED SPACECRAFT CENTER, HOUSTON

General HUMPHREYS. Mr. Chairman and members of the subcommittee, we welcome the opportunity to appear before this subcommittee and present our combined views regarding Biosatellite III and its implications related to present and future manned space flight programs.

We have much admiration for the professional competence and dedication of the investigators, engineers, and the other members of the

team who constructed and flew this most complex experiment in space biology. We consider that the objective of Biosatellite III; that is, to determine the effects of weightlessness upon the central nervous system, cardiovascular system, and certain metabolic systems of a small subhuman primate, to be a very laudable scientific goal. We did not and do not now believe that this experiment was a necessary precursor to a manned flight of any particular duration.

We have reviewed, with a great deal of interest, the preliminary information presented and look forward to the opportunity to see the final report and data analysis. Until that time, we are unable to fully evaluate the results of Biosatellite III, but we have, at this time, formed certain impressions:

1. That the data returned from the various experiments was technically good with the exception of the urine calcium study in which the values were below the range of the instrument.

2. That the physiologic alterations reported tend to validate some of the observations made in earthbound analogs of weightlessness and in manned space flight except for severity and the progression. Also these alterations seem to validate the previously postulated mechanisms such as the Henry-Gauer reflex.

3. That we now have a data point related to weightlessness in a 14-pound subhuman primate which was restrained, which was invaded by multiple instrumentation, generally unclothed, limited to fluid intake by experiment protocol, removed from terrestrial periodicity stimuli, and could not understand the environment in which he had been placed, nor take any independent action in his own behalf.

4. That from the information furnished we do not know the cause of death of this animal, although a number of contributing factors can be postulated. Among them are the multiple invasions of the brain, the vascular and urinary systems; the hypothermia, the negative fluid balance approximating the total normal circulating blood volume; attendant alterations in the balance of body electrolytes such as sodium and potassium; all these coupled with the stresses of launch, reentry, and recovery.

5. That the information derived from this flight of one small subhuman primate for 8 days, although scientifically interesting, is, in our opinion, enormously outweighed by the experience and information obtained in over 5,000 U.S. man-hours of space flight involving some 25 different subjects in flight durations ranging from a few minutes up to 14 days, approximately. In only the earlier of these missions did some of the flight environments, such as restraint, approximate those of this primate flight. When the Soviet manned flight experience and the Kosmos 110, in which the Soviets flew two dogs with somewhat similar measurements, is added, the scale tips even further toward putting Biosatellite III in its proper perspective; that is, an additive data point derived from direct in-flight measurements on a single subject of a different species, which validated some previous theories, but, in our opinion, did not produce any significant new information.

We do not wish to convey to the subcommittee the impression that we think we have all the answers or have solved the problems of

manned space flight; quite the contrary is true. We have learned a lot, but we are the first to admit that there is much to do both on the ground and in flight before we can say that in a given environment man can safely and effectively travel and work in space for long durations. We are the first to state that we would be much happier if there could be more related work conducted in the biomedical field, but we would like to point out that it is of primary importance to first address those questions which appear to be most pressing; that is, those physiological changes which we have identified in previous flights.

During manned space flight and in ground analog simulations, we have identified certain physiologic alterations which appear to be fairly constant and which are probably most important. In the central nervous system, there have been sleep disturbances and vestibular aberrations. Acceptable accommodation has occurred to both of these in a few days. There has been weight loss of up to 8 percent of total body weight in 14-day flights, most of it water loss occurring in the first 3 to 4 days, and the remainder probably tissue or lean mass loss. There has been cardiovascular deconditioning as shown by decreased orthostatic tolerance and decreased exercise capacity.

There has been musculoskeletal deconditioning evidenced by some bone mineral decrease and perhaps by lean body weight loss. There have been alterations in certain hormonal systems, but the measurements were done postflight and their significance is not yet clear to us. None of the alterations have been of such severity as to compromise crew safety or significantly degrade performance in any flights to date. Thus, it appears that man, reasonably well supported, can accommodate to the space flight environment which we have provided him today. The most significant effects of space flight appear to be related to return to the normal earth environment. Even these effects revert to earth-normal values within a period of a few hours to a few days.

Although we have confidence that man can survive and work effectively for long periods in space, during the present and upcoming Apollo lunar exploration flights we will continue to gather as much information as the mission objectives will permit. As you gentlemen know, we had planned a limited number of in-flight medical measurements for Apollo, but the operational constraints prevented us from implementing them except as detailed pre- and post-flight evaluations and comparisons. We look forward to the Apollo applications flights because one of the primary objectives of this program is to determine and evaluate man's physiological responses and aptitudes in space, and his postmission adaptation to the terrestrial environment, through a series of progressively longer missions, including evaluation of need for artificial gravity and the increments by which mission duration can be increased.

A number of biomedical experiments related to these objectives have been approved. At this moment, the ground-based studies and the hardware development for these experiments is in progress to meet the flight schedules. The studies to be carried out on man in the

Apollo applications program represent our first real opportunity to serially investigate the effects of the weightless environment on man. The experiment protocols are designed to give us data not only upon the severity of observed phenomena, but upon the time course, the mechanisms of production, and methods of controlling or alleviating any adverse effects. We will address such questions as fluid balance, metabolism, energy costs of work, cardiovascular and musculoskeletal deconditioning, sleep status, vestibular aberrations, immunologic effects, and others. In addition, we will be flying devices capable of measuring the mass of small objects such as food not consumed, feces, and other small mass; a large mass measurement device with which we can determine weight changes in the crewmen on a daily or more frequent basis if necessary, and a lower body negative pressure device. The later is designed not only to contribute to the understanding of cardiovascular dynamics in weightlessness, but also may be a promising means of protection against cardiovascular deconditioning. We are very hopeful and optimistic that during this program there will be an opportunity to have a medical astronaut on board to act as a trained observer, experimenter, and monitor.

There are two facts about the Apollo Applications program that deserve mention. First, the missions are open ended, that is, they are planned for maximum durations of 28 and 56 days, but can be terminated earlier if determined necessary. We have a high level of confidence that man's capabliity will not be cause for early termination. Second, this program is but the beginning of in-depth studies on man in the space environment and will not provide all the information we believe we will need to certify man for long durations in space.

The space station/space base design concepts provide for biological, biomedical, and biotechnology laboratory modules wherein we can adequately study the effects of space flight on a wide spectrum of living organisms including man. The design rules also require provision for both zero and artificial gravity at various levels. Because the spacecraft will be large enough, we foresee having trained observer/experimenters on board carrying out studies on man and concurrently on appropriate animals to find the answers to the questions which face us.

The performance of in-flight investigations will require an advance in the state of the art in bioinstrumentation and measurement systems. Looking toward that goal, we have been working on such a system for several years—we call it the integrated medical behavioral laboratory measurement system or IMBLMS for short. It is a modular flexible system with wide capabilities to make in-flight measurements in physiology, biochemistry, and the behavior/performance areas. Work is also going on to add other capabilities in such fields as microbiology and toxicology. IMBLMS is being developed to be applicable to man, but its capability can be extended to other animals as well. Breadboard models of this system will soon be delivered to the Manned Spacecraft Center by the two competing contractors for testing. Early in the fiscal year 1971, we will be ready to proceed with the development and production of a first order flight system. The mature system is

being planned for incorporation into a space station but certain components probably can be ready for flight earlier if required.

We, in NASA, in conjunction with various advisory groups such as the Space Medicine Committee of the National Academy of Sciences and the Biomedical Subcommittee of the Science and Technology Advisory Committee, are currently looking again at the question of the necessary biomedical program for the next decade. We are looking at studies, in addition to those already in the Apollo Applications program, which must be done on the ground and/or in flight to give us the highest possible confidence in the safety and effectiveness of man for flights of durations such as would be required for a journey to a planet such as Mars. The space-station concept and a low-cost earth-to-orbit transportation system will provide us with great flexibility in the study of man because we are not forced to commit man to long durations in space, but we can, by shuttling back and forth, extend his stay time as cautiously as our findings and supportive devices may demand. In summary, we believe that our approach to "space-rating man" is a logical and reasonable one of step-by-step extension of stay time with observations being made all the way along. The rate at which we can extend man's stay time in space will certainly depend upon the findings in each step, technology of measurement and data retrieval, and analysis and support available for each mission or step.

Such a program is and must be dynamic, changing as required within the constraints of the space flight system technology. It is and must be constantly reevaluated on the basis of new knowledge, new techniques, and new capabilities. The applied research to be done both on the ground and in flight must be redefined as often as necessary in response to the questions deemed most pressing. It must today follow the traditional methods of biological research; that is, utilization of appropriate animals and man as subjects. But, it must be alert and ready to apply newer techniques such as mathematic systems modeling and validation when they mature. We believe the program we are following is taking us in the right direction. As biomedical scientists, we would prefer it to be much more extensive, but we too require funds and the skilled people to increase and carry forward the effort.

We believe that Biosatellite III was a scientifically interesting and productive experiment in space biology, but for the reasons we have mentioned it is not cause to consider basic changes in the progress of the manned program. We believe that it is essential to plan future manned systems so that biomedical scientists and biologists can have the opportunity to adequately study the effects of space flight on man and other animals in a steadily progressing series of space experiences. We are confident that our plans for ground-based research, flight experiments, and observations, if carried out, will insure the best possible protection of man from any serious deleterious effects from space flight, and will enhance his capabilities as an operator and observer in space. We are also confident that the work being done in this regard will have a wide application to terrestrial man.

One of the best examples that we could cite is a successful, mature, integrated, medical behavioral laboratory measurement system.

Mr. Chairman and members of the subcommittee, we wish again to thank you for the opportunity of appearing before this subcommittee, and we stand ready to answer any questions which you may have.

We have also brought with us a more detailed summary of pertinent information, if you desire to have it for the record.

(The summary referred to follows:)

SUPPLEMENTAL INFORMATION TO ACCOMPANY STATEMENT OF MAJ. GEN. J. W. HUMPHREYS, JR., AND DR. CHARLES A. BERRY

This document briefly outlines the history of biomedical research and practices in support of manned space flights. In addition it comments on the relevance of the Biosatellite III data to manned space flight.

From the beginning of the space program—during the "Sputnik era"—there were dire predictions of the disastrous effects that would befall man if he were suddenly launched into the space environment. These predictions, listed in Figure 1 on the following page, were made by responsible and respected members of the scientific community. One of these predictions concerned the possibility of complete circulatory collapse in space. So disquieting were these prophecies that the chimpanzees Ham and Enos were placed in orbit to demonstrate the safety and reliability of the spacecraft and it's life-support systems, and to dispel the fear that a living subject could not survive space flight.

Following these initial animal flights the manned flights of the Mercury and Gemini programs cautiously extended man's staytime in space. Using the concept of doubling successive mission durations, these flights culminated in the 14-day flight of Gemini VII. This doubling concept has its limitations, however, particularly when we consider missions of over 120-days' duration.

In the early flights of Mercury and Gemini, weight, volume, and time constraints were such that we were limited to inflight safety monitoring and pre- and postflight biomedical measurements. In the longer Gemini flights, particularly in Gemini VII, a number of inflight biomedical experiments were performed. The experimental philosophy in those early days was to examine as closely as operationally feasible, the effect of space flight on those body systems which were known to be influenced by gravity and were therefore potential problem areas; the cardiovascular system, the musculoskeletal system, the central nervous system, and the vestibular system.

Pre- and postflights studies of blood volume changes, exercise tolerance, and cardiovascular stress were carried out. The biomedical findings published in numerous past reports are summarized in this report.

FIGURE 1.—EARLY PREDICTIONS OF MAN'S RESPONSE TO SPACE FLIGHT AND ACTUAL OBSERVATIONS

PREDICTED	OBSERVED
1. High Micrometeorite Density.	Low Micrometeorite Density.
2. Cabin and Suit Pressure Difficulties.	No Malfunctions or Problems.
3. Toxic Atmosphere.	No Toxic Contaminants.
4. Temperature Extremes.	Minimal Variation About Comfort Zone.
5. Radiation Hazard.	Minimal Radiation Doses, All Inconsequential.
6. Isolation Effects.	Crews Have Never Felt Isolated.
7. Physical Confinement Effects.	Observed, But Tolerable in Gemini—Less Evident in Apollo.
8. Weightlessness Effects.	Adaptation Appears to Occur—Well Tolerated.
9. Response to Gravity Loads.	Gravity Loads, No Problem With Performance.
10. Dysbarism.	None.
11. Disruption of Circadian Rhythms.	Noted—No Effect on Performance.
12. Decreased g-Tolerance Following Weightlessness.	Minimal—Return to Normal is Rapid.
13. Skin Infection and Breakdown.	Dryness, including dandruff.
14. Sleepiness and Sleeplessness.	Interference (minor).
15. Reduced Visual Acuity.	None.
16. Unpredicted.	Occasional Eye Irritation.
17. Unpredicted.	Nasal Stuffiness and Hoarseness.
18. Disorientation and Motion Sickness.	No Disorientation; Motion Sickness Rare.
19. Pulmonary Atelectasis.	None.
20. High Heart Rates.	Launch, Re-entry, Extravehicular Activity.
21. Cardiac Arrhythmias.	None.
22. High Blood Pressure.	None.
23. Low Blood Pressure.	None.
24. Fainting Postflight.	None.
25. Electromechanical Delay in Cardiac Cycle.	None.
26. Reduced Cardiovascular Response to Exercise Inflight.	None.
27. Unpredicted.	Absolute Neutrophilia.
28. Reduced Blood Volume.	Moderate.
29. Reduced Plasma Volume.	Minimal.
30. Unpredicted.	Decreased Red Cell Mass—Gemini.
31. Dehydration.	Minimal.
32. Weight Loss.	Variable, up to 10 Lbs.
33. Bone Demineralization.	Minimal Calcium Loss.
34. Loss of Appetite.	Varying Caloric Intake.
35. Nausea.	Isolated Instance—Apollo.
36. Renal Stones.	None.
37. Urinary Retention.	None.
38. Diuresis.	None.
39. Muscular Incoordination.	None.
40. Muscular Atrophy.	None.
41. Unpredicted.	Reduced Exercise Capacity Postflight.
42. Hallucinations.	None.
43. Euphoria.	None.
44. Impaired Psychomotor Performance.	None.
45. Sedative Need.	Only for Extreme Work-Sleep Time Changes.
46. Stimulant Need.	Before Re-entry Occasionally.
47. Infectious Disease.	Occasional—Incubating Prior to Launch.
48. Fatigue.	Minimal.

An important cardiovascular finding was the decreased orthostatic tolerance to standing immediately after each of the later Mercury flights. This cardiovascular deconditioning, manifested by decreased blood pressure and increased pulse rate, has been noted in each of the astronauts immediately postflight. This phenomenon is short-lived, disappearing within 24 to 48 hours post-flight, and is apparently the result of multiple factors including small volume presenting free movement, weightlessness, dehydration, and possibly fatigue. Nearly identical cardiovascular changes have also been reported by Professor V. V. Parin and his associates in *Acta Cardiologica* (1965) as follows:

"Investigations of the heart and circulation under weightless conditions have shown significant changes to occur in the intra- and extracardiac hemodynamics which cannot however be interpreted as pathological ones."

Dehydration or loss of water, but not of salts, from the body has been consistently noted in astronauts in the immediate postflight period. This was manifested in weight loss of up to 10 pounds in some astronauts and is relatively independent of the duration of fight. This loss of 6 to 7 percent of the astronaut's body weight is due principally to water deficits. Most of the loss is restored by rehydration during the first 24 to 36 hours post-flight. Increased metabolic heat production, particularly if the astronaut is engaged in strenuous extravehicular activities in the pressurized suit is an additional factor contributing to fluid loss. Russian investigators have reported dehydration to a similar degree in their cosmonauts. Detailed data regarding fluid and electrolyte changes observed in American astronauts are cited in the attached report.

Plasma volume and red blood cell mass changes have been measured in three Gemini and early Apollo flights. In general, there was an overall moderate loss of plasma volume. In the Gemini series, a loss of red blood cell mass up to 20 percent was documented. The current feeling is that this loss of red cells was due principally to the hyperoxic environment (100 percent oxygen atmosphere) in the Gemini spacecraft. In the Apollo series, in which the concentration of oxygen was reduced by adding small amounts of nitrogen in the spacecraft atmosphere, no significant red cell losses have been observed.

Additional significant medical results from Gemini were a moderate loss of exercise capacity, a minimal loss of bone density, and a minimal loss of calcium and muscle nitrogen. In the Apollo spacecraft, the astronauts were provided for the first time with enough cabin room to allow freedom of movement and some exercise; a significant change over the confinement in the Mercury and Gemini programs. This increased activity had a salutary effect on essentially all of the biomedical parameters measured. Although some degree of postflight cardiovascular deconditioning, dehydration, and diminished exercise capacity has been noted following the Apollo flights, all of these effects were less pronounced and of less duration than in Gemini. Thus, with improvement in spacecraft design to provide an environment that increasingly resembles that of Earth, the stresses of space flight on man are reduced in severity. Future programs will continue this trend.

The high metabolic expenditure of the early Gemini flights, in which there was increased sweating, was largely due to ambitious mission programming, the resistance to movement of the rigid pressurized suit, and inadequate simulation for training purposes. These difficulties were later overcome by underwater preflight simulations at neutral buoyancy, improved spacesuit mobility and flexibility, and more favorable timing of crew activities.

To a limited extent, certain of the Biosatellite III data tended to confirm existing knowledge of the effects of space flight (particularly of weightlessness) on man. Marked species difference in response, and therefore difficulty in extrapolating from one species to the other, is evident when the data from the manned flights is compared with those from Biosatellite III. The degree of dehydration observed in Bonny has not been noted in any of the United States manned flights even up to 14 days' duration nor has it been reported in the Russian Cosmonauts. In the Soviet Cosmos 110 Flight, two dogs lost 26 percent and 29 percent of their body weight within 3 days. Half of this, which was apparently fluid and electrolyte loss, was regained within 10 days.

Our present knowledge concerning the effects of space environment on living forms is derived from three principal sources:

1. Ground-based animal studies.
2. Ground-based human studies.
3. Manned space flight experience.

As manned flight experience has grown, there has been less dependence on ground-based human and animal studies. The ideal subject for determining mans response to space flight is man himself. Accordingly in the Apollo Applications Program, great emphasis is placed on critical biomedical experiments to prepare man for extended space flight. This approach relies upon increasingly effective real-time inflight measurements on man, and complementary man-attended animal experiment examining a single body system at a time, to obtain information which cannot be obtained on man for ethical or safety reasons; including studies aimed at elucidating biological mechanisms; and finally, computer-supported, mathematical modelling of human body systems. The latter, now in its infancy, may ultimately become an effective, predictive tool in the biomedical armamentarium.

The loss of bone density as described in Bonny is a well documented phenomenon noted in the Gemini and early Apollo flights but the findings have varied with individuals and have not been of such severity as to be significant. Both the astronaut and Biosatellite III measurements were performed by Dr. Pauline Berry Mack. The loss in bone density is due largely to a loss of mineral salts most evident in the weight bearing bones, and is dependent on such variables as dietary mineral intake and physical exercise of the bone compression type.

The alteration in circadian rhythmicity in Biosatellite III has also been noted in manned space flights, as well as in aircraft travelers crossing multiple time zones. In astronauts these alterations have not always been identical among crewmen on the same flight. For instance in the 4-day flight of Gemini IV, one considerable disruption of his cycle as shown by continuous heart rate recordings, astronaut maintained his normal circadian rhythmicity while the other had In no case, however, has there been any serious decrement in performance as a consequence of rhythm disturbance. In general, the problem has been minimized in manned space flights by inflight work/rest cycles which coincide with Cape Kennedy day/night cycles. Important in man's tolerance to altered circadian rhythm are his recognition of the phenomenon in himself, his ability to reason, use judgment, and respond to instructions.

The Rapid Eye Movement (REM) sleep data of Biosatellite III indicating the kind of sleep associate with dreaming are very interesting because there is also evidence from crew debriefings that dreaming does occur during inflight sleep periods of the astronauts. Such REM sleep is thought to be necessary for the continued long term well-being of man and coincides with manned space flight information.

Electroencephalographic (EEG) recordings were obtained during the first four days of Gemini VII on Astronaut Borman. Dr. W. Ross Adey was one of the principal investigators for this manned space experiment which documented sleep at all levels including the REM type. In general, the relatively minor sleep difficulties encountered in the early manned flights have been resolved by conformance to Cape Kennedy day/night cycles, and by having all crewmembers sleep at the same time insofar as is possible to avoid mutual sleep disturbance among crewmen.

The sweating reported from Biosatellite III, has also been experienced by astronauts during high metabolic expenditures of strenuous extra vehicular activity (EVA) in the early Gemini flights. The resulting loss of fluid and salt posed no real problem for the astronauts, as these were replaced to a large extent by voluntary food and water intake. Indeed, in the 14-day Gemini VII flight in which the astronauts were encouraged to eat and drink according to a programmed plan, there was no discernible change in the effective circulating blood volume as measured in the immediate postflight period as compared with the preflight values. Thus some dehydration secondary to excessive sweating has occurred during high work loads in manned flight, but has posed no serious problem in that man of his own volition replaces the water and mineral loss by adequate ingestion.

The rather pronounced and persisting diuresis reported in Biosatellite II and attributed to the Henry-Gauer reflex has not been noted in any of the astronauts, subjectively in any flight or in the urine output measurements of Gemini VII. A diuretic response has been observed in man during simulation of weightlessness in water immersion studies and to a lesser degree during initial phases of prolonged bed rest. The diuresis occasioned by weightless simulation in man is usually transient and generally not a sustained phenomenon.

The Henry-Gauer reflex is only one of several mechanisms by which the body strives to maintain equilibrium among the body fluid compartments, particularly with regard to circulating blood volume in the face of stresses which tend to disturb fluid balance. If one presumes that the Henry-Gauer reflex is operative in man during weightlessness, its function would seem to be adaptive in nature, to decrease circulating blood volume, and in turn the volumes of the body fluid compartments that are in equilibrium with it. In any case, should excessive in-flight loss of fluid and electrolytes tend to occur in man these can be readily restored and dehydration prevented by voluntary fluids and salt intake. With regard to dehydration aggravated by sweating or evaporative fluid loss, man has a distinct advantage over sub-human primates because of his much more favorable surface-to-mass ratio. If necessary, water and electrolyte intake can be adjusted in man to prevent excessive dehydration. This has so far not been required in the manned flight program, as the changes have been adaptive, non-pathological, and readily corrected.

In summary, man has done far more than merely survive in the space flight environment. His performance in complex operational tasks has been truly remarkable and has in no way been adversely influenced by any of the adaptive physiological changes that have been observed. Although animal flights are certainly not prerequisite to a manned program, appropriate man-attended animal experiments with the complex invasive instrumentation which they allow may be desirable.

The uncertainty inherent in extrapolating data from subhuman species to man is well recognized. Thus, wherever possible direct biomedical measurements must be made on man himself in the space environment.

The physiological changes observed in man to date are adaptive in nature and not life-threatening. Further, countermeasures are available to prevent, reverse, or ameliorate those adverse changes should such action become necessary. The biomedical investigations of the Apollo Applications Program will provide adequate information to prepare man for missions extending up to 56 days. Animal studies are not believed to be required in this phase. We do forsee a possible requirement for man-attended animal experimentation in the Space Station/Space Base type of facility. In the latter, valid biomedical information can be acquired to enhance understanding of basic mechanisms operative in man's responses to weightlessness and to other stresses in space. In a space station animal, experimentation may be of value in contributing to the understanding of man's capabilities for indefinite habitation in space. Animals should be used in the same manner as they would be in a ground based laboratory i.e., to get information on problems identified where it is not feasible or practical to obtain the data on man.

Report of Fluid/Electrolyte Changes Observed in U.S. Manned Space Flights Accompanying the Statements of Maj. Gen. J. W. Humphreys, Jr., and Dr. Charles A. Berry

Normal mechanisms maintaining physiological homeostasis will produce a net fluid loss upon exposure to hypodynamic and/or hypogravic environments. Weight change may be considered to reflect, at least in part, body fluid shifts and losses. Hence, postflight changes in crewmembers' weights can be used as a gross measure of fluid losses consequent to space flight.

Pre- and postflight weights for Gemini and Appollo crewmen and for crewmen of multiple flights are shown in Tables 1, 2, and 3 respectively. An average weight loss approximating 6 pounds is observed overall. There is no significant difference between Gemini and Apollo results. Findings for individual crewmen are generally consistent in subsequent flights. These averages do not, however, include obvious variations between and within individual, nor is any correlation attempted for mission duration, cabin atmosphere, or degree of confinement in different spacecraft. By about 24 hours postflight over half of the weight loss is regained. This tends to support the allegation that fluid loss accounts for a major portion of observed postflight weight loss. However, few, if any, significant clinical symptoms have been observed attributable to fluid loss alone.

Plasma volume and red blood cell mass have been measured in three Gemini and three Apollo flights. Results are shown in Table 4. No averaging of these results is felt justified because of the gross individual differences, the relative inaccuracy of measurement techniques, the different atmospheric exposures affecting additional mechanisms involved in red blood cell homeostasis, and the rela-

tively unknown interrelationship between plasma volume and red blood cell mass. However, an overall loss of plasma volume may be generalized, despite the gains shown in Gemini 7 crewmembers.

Only the Gemini 7 flight included attempts at measuring inflight intake and output. These are shown in NASA–S–66–7752, NASA–S–66–7753, NASA–S–66–7754, and NASA–S–66–7755. Only gross impressions are justified here, but fluid intake was apparently nearly double the recorded urinary output throughout the flight for both crewmembers. Further, urine assays showed a relative increase in sodium and potassium retention and in aldosterone levels postflight.

Pre- and postflight urinary sodium and potassium values of Apollo 7 and 8 crewmen have shown no significant alterations. However, those of Apollo flights 9, 10, and 11 displayed a definite postflight trend toward decreased excretion of sodium and potassium, at near $p<0.05$ significance level.

No consistent pattern has evolved from serum electrolyte analyses from any flights. This is supported by the fact that homeostatic mechanisms tend to maintain these values within normal limits so long as possible. Gross alterations would be evidenced by clinical signs and/or symptoms and no indication of clinical disequilibrium has been observed on any manned flight to date.

Urinary osmolality is a very sensitive indicator of adaptive effects. Table 5, showing pre- and postflight urine osmolalities from Apollo flights, indicates no decisive trends. Serial analysis of each postflight voiding for 48–72 hours would be needed to gain meaningful data regarding readaptation upon resuming earth activity. Similar inflight measurements must also be obtained to assess the time-course and magnitude of flight adaptations.

On Gemini 7, postflight hormonal assays have shown modest aldosterone elevations in both crewmembers and on Apollo 9 and 10 highly significant elevations of angiotension for all six crewmembers.

SUMMARY

1. Body fluid losses in U.S. manned space flights have been consistently demonstrated by decreased postflight body weight (averaging about 6 pounds), over 50 percent of which is regained within 24 hours. On those flights when plasma volume was measured, a postflight decrease has generally been observed.

TABLE 1.—GEMINI MISSIONS

[Body weights (pounds)]

Mission and duration	Crewmen	Preflight	2-hour postflight	Difference	24-hour postflight	Difference
III—5 hours	Grissom	158.0	155.0	−3.0		
	Young	164.3	162.8	−1.5	164.3	0.0
IV—4 days	McDivitt	156.5	152.0	−4.5	154.5	−2.0
	White	173.0	164.5	−8.5	167.0	−6.0
V—8 days	Cooper	152.0	144.5	−7.5	149.3	−2.7
	Conrad	154.0	145.8	−7.2	158.5	+4.5
VI—26 hours	Schirra	176.3	173.7	−2.6		
	Stafford	171.0	161.0	−10.0		
V—14 days	Borman	162.5	152.5	−10.0	157.0	−5.5
	Lovell	169.5	163.5	−6.0	164.5	−5.0
VIII—11 hours	Armstrong	162.7				
	Scott	173.0				
IX—3 days	Stafford	174.0	172.0	−2.0	172.3	−1.7
	Cernan	172.5	164.5	−8.0	166.0	−6.5
X—3 days	Young	163.0	159.0	−4.0	163.0	0.0
	Collins	163.5	156.0	−7.5	165.5	+2.0
XI—3 days	Conrad	152.7	150.0	−2.7		
	Gordon	151.0	151.0	0.0		
XII—4 days	Lovell	170.0	160.3	−9.7		
	Aldrin	166 0	161.3	−4.7	162.0	−4.0
			n=	18		12
			$\bar{X}$=	−5.5		−2.5
			SD=	3.2		3.7
			range=	0, -10.0		+4.5, - -6

2. Serum osmolality and electrolyte balance have been uniformly maintained and no significant relevant clinical findings have been noted.

3. Postflight urine osmolality values have varied widely, but serial postflight measurements have been insufficient to warrant any definite conclusions at this time.

4. Highly significant angiotension-aldosterone changes have been documented in postflight Apollo. These observations require clarification as to time course and frequency (increased "n").

5. Inflight urinalysis capability, immediate postflight serial urinalyses, and a detailed historical documentation of inflight symptomatology relevant to fluid/electrolyte alterations are firm requirements for a thorough understanding of fluid and electrolyte changes incident to man's adaptation to the space environment.

TABLE 2.—APOLLO MISSIONS

[Body weights (pounds)]

Mission	Duration (days)	Crewmen	Preflight	ASAP	Difference	24-hour postflight	Difference
7	11	Schirra	194.3	188.0	−6.3	190.5	−3.8
		Eisele	157.0	147.0	−10.0	150.5	−6.5
		Cunningham	156.0	148.0	−8.0	153.5	−2.5
8	8	Borman	169.25	160.5	−8.75	163.25	−6.0
		Lovell	171.8	164.0	−7.8	164.75	−7.0
		Anders	142.0	138.0	−4.0	138.5	−3.5
9	10	McDivitt	158.75	153.5	−5.25	156.25	−2.5
		Scott	178.25	172.5	−5.75	181.0	+2.75
		Schweickart	159.12	153.0	−6.12	157.25	−1.9
10	8	Stafford	170.5	168.5	−2.0	170.75	+.25
		Young	165.25	159.5	−5.75	161.25	−4.0
		Cernan	172.5	163.0	−9.5	164.25	−8.25
11	8	Armstrong	171.5	164	−7.5	170.0	−1.5
		Collins	166.0	159	−6.0	159.0	−6.0
		Aldrin	167.25	166	−1.25	170.0	+2.75
		n			15		15
		$\bar{X}$			−6.3		−1.5
		SD			2.5		8.0
		Range			−1.25, −10.0		+2.75, −8.25

TABLE 3.—U.S. MANNED SPACE FLIGHT SUMMARY OF MULTIPLE MISSION CREWMEN PREFLIGHT VERSUS POSTFLIGHT WEIGHT CHANGES (POUNDS)

Crewmen	Duration (days)	ASAP	+24 hours	Duration (days)	ASAP	+24 hours
Schirra	1	−2.6	+1.2	11	−6.3	−3.8
Borman	14	−10.0	−5.5	8	−8.75	−6.0
Lovell	14	−6.0	−5.0	8	−7.8	−7.0
	4	−9.7				
McDivitt	4	−4.5	−2.0	10	−5.25	−2.5
Scott	½			10	−5.75	+2.75
Stafford	1	−10.0	[1] −3.0	8	−2.0	[1] +.25
Young	¼	−1.5	.0	8	−5.75	−4.0
	3	−4.0	.0			
Cernan	3	−8.0	−6.5	8	−9.5	−8.25
Armstrong	½			8	−7.5	−1.5
Collins	3	−7.5	+2.0	8	−6.0	−6.0
Aldrin	4	−4.7	−4.0	8	−1.25	+2.75
	n=	11.0	9.0		11.0	11.0
	$\bar{X}$=	−6.2	−2.2		−6.0	−.8
	SD=	3.0	3.2		2.5	9.3
	Range=	−1.5, −10.0	+2.0, −6.5		−1.25, −9.5	+2.75, −8.25

[1] + 48-hour values not included in 24-hour averages.

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TABLE 4.—CIRCULATING VASCULAR VOLUME AND RELATED CHANGES (GEMINI-APOLLO)

	Gemini 4		Gemini 5		Gemini 7		Apollo 7			Apollo 8			Apollo 9		
	CP	P	CP	P	CP	P	C	CMP	LMP	C	CMP	LMP	C	CMP	LMP
Total blood volume percent	−7	−13	−13	−13	0	0	−4	−1	−6	−9	−10	−6	+1	−6	−6
Plasma volume percent	−5	−13	−8	−4	+15	+4	−5	+1	−4	−16	−14	−8	−4	−7	−14
Red cell mass percent	[1] −12	[1] −13	−20	−20	−19	−7	−1	0	−9	+2	−2	−4	−4	−7	−10

[1] Calculated from plasma volume and hematocrit data.

Note: 5 percent is the level of significance for plasma volume and red cell mass as measured by the techniques employed.

TABLE 5.—APOLLO URINE OSMOLALITY

		Preflight			Postflight ASA
		F-3	F-14	F-5	
VII	Schirra			591.3	543.3
	Eisele				
	Cunningham			909.7	1,224.5
VIII	Borman		77.4	97.4	38.0
	Lovell		915.9	936.2	1,199.8
	Anders		654.9	586.1	108.4
IX	McDivitt		753.0		763.0
	Scott		842.0		1,240.0
	Schweickart		972.0		992.0
X	Stafford			736.0	295.0
	Young			549.0	815.0
	Cernan			605.0	1,018.0
XI	Armstrong	701	843.0		1,162.0
	Collins	898	992.0		643.0
	Aldrin	975	733.0		850.0

Mr. KARTH. Thank you very much, General Humphreys. We appreciate greatly your coming before the committee to give us the benefit of your judgment, your viewpoint as it relates to the future of a U.S. biological scientific program, particularly as it affects man for longer duration space flight.

Mr. Chairman.

Chairman MILLER. Mr. Chairman, I have to leave in a few minutes. There are a couple of questions I would like to raise.

Mr. KARTH. Yes, sir.

Chairman MILLER. First, I would like to repeat what General Humphreys has said, and ask him to confirm his statement on page 2: "We did not and do not now believe that the experiment was a necessary precursor to manned space flight of any particular duration." In this, you referred to the little monkey that didn't quite make it. That is fundamentally your belief in this field?

General HUMPHREYS. Yes.

Chairman MILLER. Dr. Berry, you also subscribe to that?

Dr. BERRY. Yes, sir; I do, Mr. Chairman.

Chairman MILLER. Because the point has been raised, as a result of the Biosatellite III flight, in the minds of some of us, so we want to make doubly sure man can go into space and stay there for some time before we invest a lot of money in hardware and equipment. If he can't do it, it would be a waste of money.

Now, the fact that Biosatellite III was not, shall we say, successful—although I don't know if that is necessarily the word to use, but we did lose the little fellow—has caused a lot of eyebrow raising in certain directions. It is essential that we get the answers to these questions and the criticism they imply if we are going to get the full support of Congress for our space program.

I notice that you say, on page 5, "As you know, we had planned a limited number of in-flight medical measurements for Apollo, but the operational constraints prevented us from implementing them except as detailed pre- and post-flight evaluations and comparisons."

I imagine a good deal of that was the lack of money to do some of these things, is that correct?

Dr. BERRY. Yes. There was some money constraint, Mr. Chairman, but basically I think the major item here was the revamping of the program that occurred after the accident and the feeling we had to

concentrate very heavily upon the difficulties that were envisioned with this endeavor of trying to get a successful landing and return; and in view of that, experiments were pulled out of that program. We are getting a great deal of information from our preflight and postflight determinations, though. That has been very helpful for either confirming or denying the information we obtained from Gemini.

Chairman MILLER. As we go on, we should have more opportunity in future flights to do some of this than we had in the first flight, am I correct in that assumption?

Dr. BERRY. Yes, sir.

General HUMPHREYS. Yes, sir.

Chairman MILLER. Now, in your IMBLMS, General, is the Air Force cooperating with you in this field at all, your space medical people?

General HUMPHREYS. Yes; as members of the committees which look at the system. It is a NASA-managed project, but they have seen and have been kept informed of all of the work we have been doing and have had certain inputs into this.

Chairman MILLER. I believe they have great capability, and we should use it as they expect to use ours. We have to bring these two programs very closely together. This is one place where I believe it can be done.

General HUMPHREYS. I could be called prejudiced on that account.

Chairman MILLER. I believe you are.

You said, again, on page 9, "As biomedical scientists, we would prefer it to be much more extensive, but we too require funds and skilled people to increase and carry forward the effort."

I want to congratulate you, General, on a very fine statement. I only wish I could stay longer, but unfortunately, as the chairman knows, I have a few duties that have to be taken care of. I am very happy to have you here and I am very happy to see Dr. Berry here. Dr. Berry is an old and valued friend.

He asked me when I was coming down to Houston again. I would like to be down there for a flight, because maybe I would have the privilege of sitting in the blockhouse by him again where he could point out what is taking place as these people fly.

You remember, Doctor, you did this for me on one of the Gemini flights.

Dr. BERRY. Yes, sir.

Chairman MILLER. It gave me a great deal of information. I said, "Why is that thing going, why is his heart going up?" He said, "He just reached up to press a lever."

Thank you very much.

Thank you, Mr. Chairman.

Mr. KARTH. Thank you, sir. Thank you, Mr. Chairman, for coming.

Chairman MILLER. I would like to congratulate you and the committee for the fine work you are doing.

Mr. KARTH. We understand your schedule.

Mr. Mosher.

Mr. MOSHER. Mr. Chairman, this statement by General Humphreys and Dr. Berry certainly is very confident and optimistic and reassuring in its tone.

General, I note that you put a great deal of emphasis on the weight of experience and the information—I am referring to page 3—ob-

tained in over 5,000 U.S. man-hours of space flights involving some 25 different subjects in flight durations, ranging from a few minutes to 14 days, and you also mentioned the Russian experience, too.

What about this 14 days in which we have had experience with man in weightlessness? Do you anticipate that more extensive periods will show very different results?

I realize you can only guess at this, but I suppose that is the chief concern of this committee at this moment, as to whether or not we are going off rather blindly in committing ourselves to vast expenditures for hardware and that sort of thing without really knowing what the longer, longer periods of weightlessness will indicate.

All of us can only have certain judgments, but it is your expert judgment, I presume, that this is a good gamble; and on the basis of relatively brief experience we have had, you believe we can move with assurance into the longer periods and make the capital investments required for this? You are giving us that assurance, is that right?

General HUMPHREYS. No, sir; I am not assuring you that nothing can happen to man in long-duration space flight, because I don't know the answer to that question either. I do believe that the work going on and the work we see coming in the next period in programs, will give us the information we need which will allow us to either support that man adequately so that he can go for long durations or to determine that he can't for sure.

Now, I believe that most of the evidence is on the side that he can, and I don't really like this word qualifying man, because I guess if we gave him an earth environment he could do what he can do on earth, but somewhere between an earth environment and the weightless environment of space or the other environments of space, there is probably an optimum, if you like, environment in which he can work and safely work for long durations.

We don't know the total answers to that today. If we did, sir, there wouldn't be much use for us to have a research program.

Mr. MOSHER. On page 6, you say, "We have a high level of confidence that man's capability will not be cause for early termination," and second, "this program is but the beginning of in-depth studies on man in the space environment and will not provide all the information we believe we will need to certify" and so forth.

Your emphasis there is that you have to take this whole program step by step and first make your judgments on the basis of increasing evidence as you go along?

General HUMPHREYS. I think that is correct, sir, and I was specifically referring to the Apollo Applications program in that statement, one, that it is a program of definite duration and would be terminated at the end of 28 days; and if that goes well, 56 days; but during that program or during those flights, we will be measuring a great number of parameters on man in flight such as eye movements, his ability to work, cardiovascular measurements, such things as we have not been able to do in the limited volumes and so forth in Mercury, Gemini, and Apollo, and it is the beginning of in-flight measurements on man of some magnitude.

Mr. MOSHER. What probability do you think there is we may have to eventually include artificial gravity systems in some of these lengthy periods of weightlessness?

General HUMPHREYS. I wish I knew the answer to that one, sir. Of course, we hope to determine that in a program such as the space station, the real need for artificial gravity.

Mr. MOSHER. There is a genuine possibility of that need?

General HUMPHREYS. There is, sir, but the provision of artificial gravity itself poses a great number of problems, in the way it is produced and so forth, and the effects it may have on the body itself.

Mr. MOSHER. Your advice to this committee, at this point, would be that you don't see any need to cancel or hold up or reconsider in any fundamental way the present proposed pace of hardware development and the expenditure of these billions of dollars for manned space flight?

General HUMPHREYS. No, sir; not based on the knowledge we have today, I don't think we can say, hold it up. In the first place, I think the planning for the future is such it will provide us with the opportunity for studying biological systems in the weightless environment for a long period of time. We have not had that up until now.

Mr. MOSHER. Dr. Berry, did you want to say something?

Dr. BERRY. Mr. Mosher, I would like to go back in time, because I think the history is important here to realize the position in which we stand right at the moment.

If we look back prior to the first Mercury flight, there was a great deal of concern and a number of dire things were raised as possibilities by very good scientists, good investigators, who tried to take what was known, at that time, about earth-based physiology and tried to extend it to an environment which we didn't know as much about then as we do now.

This list of dire things is very long, and we listed some of these in the supplemental statement.

At that time, there was grave concern about a 15-minute space flight, and the effect it might have on the cardiovascular system of man, and we didn't have much instrumentation for our use. From aviation experience, we were very convinced that these high-heart rates would not be the problem others thought they might be. We have continued to go down that route with the manned space-flight program, trying to expose man in an incremental manner so you can examine what happens to him admittedly with limits as far as instrumentation is concerned, but trying to look at total system performance with man as the system and then to look significantly and in as much depth as could be done at a particular system when we saw evidence of change in that system. That is what has been done as we have come along in the program.

I think we need to continue that sort of experience. We are convinced from our ground-based experience where we have tried to reproduce as much of this information as possible through bed-rest studies and things of this sort as analogs of some of the weightless experience. We have tried to study this in a ground-based situation. It is not possible to duplicate exactly what happens to us in the weightless environment by any ground-based analog we know.

Now, there is ground-based research necessary. We obviously have to continue to do that at an increasing rate, but the only way we are going to get the answers to these questions is to really get that information from space flight itself. We need to actually observe the man

for increasing time periods. We need to be able to study him in depth in a space station which will give us the necessary volume and equipment.

I think that both General Humphreys and I feel very, very deeply that if you project ahead from what we have seen of man's capability thus far—I personally feel, and I won't put him in this spot. Let me rephrase, I personally feel that if we are to project ahead from where we are now, I think that man is going to show himself very capable of adapting to this environment. He has already shown the signs of capability to adapt and from our bed-rest studies—we have completed a 9-month bed-rest study—it doesn't appear, from that data, that what we can expect is a continued deterioration. Things apparently have a capability of plateauing and not continuing to deteriorate, and I think that is what we will see in our space-flight experience. I think the worst thing that could happen to us is we might have to provide some sort of aid, protection, when he comes back to the 1-g. environment.

I think he will adapt very well to the 0-g. environment, and will be able to continue the work for long periods of time there.

Mr. MOSHER. As I interpret the tone of your testimony, it tends to deemphasize rather completely any necessity for advance experiments and testing with primates.

Dr. BERRY. Yes, sir.

Mr. MOSHER. You seem to feel very strongly that a lot of work with primates isn't necessary and you can go right ahead with a carefully paced experimentation with man himself.

Dr. BERRY. Yes, sir; and maybe I ought to explain that, because I am not suggesting you never use primates for anything, because that is not my belief. I do feel, though, that it is very difficult to translate information obtained from animal experiments directly to the man situation, and it is particularly difficult depending upon the circumstances of a given experiment, with instrumentation and things involved. Mechanisms in animals are not always the same as they are in man either and there are many instances of erroneous data concerning man being obtained in experimental animals.

I think the thing we can do with animals is look in depth at a particular mechanism which is the type of thing you do with animals here on the ground, and once we find some particular thing we want to examine in depth with procedures you would not want to do on man, then I think those are the things you ought to do in flight. I think that that is the way we ought to use animals where they can be tended in a manned laboratory the same way you would here on the ground.

Mr. MOSHER. You are saying animal experimentation supplements the experimentation with man, but it doesn't require that it precede that?

Dr. BERRY. No, sir.

Mr. MOSHER. Mr. Chairman, I guess I have taken up enough time.

Mr. KARTH. Thank you, Mr. Mosher.

Mr. Symington.

Mr. SYMINGTON. Thank you, Mr. Chairman.

Today's testimony certainly seems to conflict, General, in the judgment that you have given us, with the testimony we had last week

in which it was suggested by one or two of the witnesses that in a 28-day manned flight, difficulties would be expected.

First, I would like to ask on the flight of the monkey, was that something over which you had to sign off before the monkey went up? Is that an experiment in which you are interested from its inception?

General HUMPHREYS. We were aware of the experiment. We had no authority over the experiment in any way, shape, or form. We were aware of it, aware of its progress, but we did not have to sign off before it flew at all, sir.

Mr. SYMINGTON. If your judgment had been solicited as to the need for that particular flight, would you have been negative on it?

General HUMPHREYS. As a precursor to man, yes, sir: as an interesting space biology experiment, I would not have said, no flight.

Mr. SYMINGTON. I do derive from your testimony which certainly at best—and I use the word advisedly—is patronizing concerning the value of the monkey flights. I do derive, from your own direct statement, that about all we learned from the flight was what happens to a 14-pound monkey. And, I am not sure in my own mind whether you feel that is really necessary. You call it a laudable scientific goal. What is laudable about it? Because there are so many other animals we could send up in space. It would be laudable to find out what happens to an elephant; so there must be some information that we are trying to extrapolate that is of value to our human flight program. But as far as you are concerned, that is not so?

General HUMPHREYS. I think that was the hope. I don't think that that was really—or maybe I am incorrect—the basic reason for flying the experiment, to say that this will happen to man. I think the primary objective was to try to determine what the mechanisms are of changes that occur in weightlessness, and certainly I don't want to instrument man in the way this animal was instrumented. I don't think man would want to be instrumented either, not today, and so, from that standpoint, I think it was a laudable experiment.

I did not and still don't believe that it was necessary as a precursor to manned flights of a duration of 28 days. I think that what we learned from it was interesting and confirmed a great many things we thought were happening. I don't believe you can say that we really learned what happens to a 14-pound monkey in the weightless environment. There were a great many factors involved. We learned what happened to a 14-pound monkey under these experimental protocol conditions.

Mr. SYMINGTON. Supposing the monkey had emerged after completing the full flight and hopped up and grabbed a banana and swung on a tree as before. Would that have encouraged you any at all about the prospects for man in space more than you were encouraged by what actually happened to the monkey?

General HUMPHREYS. I don't believe it would have encouraged me any more than I am encouraged at the moment from the data which is preliminary at the moment. I don't think it has changed our ideas about man. I think it has buttressed up our understanding of some of the mechanisms involved, but that is about all, sir.

Mr. SYMINGTON. One further question, Mr. Chairman, to Dr. Berry, who has indicated to us this morning that man can adapt to weightlessness.

You didn't put a time duration on that statement. The testimony last week strongly indicated the advisability of an artificial gravity on very long trips. I take it you don't believe that would be necessary even for a martian trip?

Dr. BERRY. No; Mr. Symington. At the present time, I don't think we have any medical evidence that would indicate that we have to provide gravity at this point in time, realizing that we have data through a 14-day period. I think that there are many reasons that people in the program believe that gravity would be a valuable thing to have from a habitability standpoint, and that is still something that is being discussed at great length within the agency, and I think we need to have that as a tool in a space station to investigate, to find out what kind of problem it creates, as well as what it might alleviate; but I don't think we have any evidence today to say we have to have it for medical reasons.

Mr. SYMINGTON. Do I take it you consider a state of weightlessness concerning its effect on the physiology of man to be really equivalent to a normal 1-g. gravity condition?

Dr. BERRY. No, sir; I did not say that. It is not equivalent certainly. There are changes which we have measured, but these things appear to be adaptive changes to an environment which is in a sense less demanding. For instance, as far as the cardiovascular system is concerned, because of the lack of weight of the column of blood, the heart adapts and, in essence, does less work and, therefore, certain changes occur in blood volume. We see certain changes occur as far as calcium and as far as muscles are concerned. These are adapting that individual to that particular environment.

Most of the change that we have measured today has been when he comes back to the 1-g. environment and is required then to suddenly readapt himself and to be in an environment which is more demanding than the condition in which he was—weightlessness.

As a result of that, I think it is imperative that on these longer duration flights we not only have the capability to measure man in flight, but that we measure the readaptive process after coming back to earth.

Mr. SYMINGTON. And that we get him back alive.

Dr. BERRY. Yes, sir.

Mr. SYMINGTON. Much as we like to get deep sea divers up without pressing them in a decompression tank.

Dr. BERRY. Absolutely.

Mr. SYMINGTON. Yet it is still your judgment there is no limit to the weightlessness that he can endure and still return and go through reentry and come back alive?

Dr. BERRY. I would like to have the data. I would not take the data we have from 14 days and extrapolate and say man can necessarily do a 2-year mission. I think we would be very foolish, from a medical standpoint, to do that.

I feel perfectly confident in looking at the 28-day flight. I would like to look at that data then and I would like to then take the next step based upon the things we find. I think that it is important we do it that way. If you asked me for my own personal deep feeling based upon the experience to date, I would have to say we anticipate we probably are going to find man will be able to adapt here, but I think

it is terribly important to have this data and be very sure of each one of these steps, and I don't think we can extrapolate to anything, but the next step.

Mr. SYMINGTON. There is mention, on page 4, of certain cardiovascular deconditioning, decreased exercise capacity, musculoskeletal deconditioning, some bone mineral decrease, and lean body weight loss. I take it that is in the manned flight of 14 days?

Dr. BERRY. Yes, sir; and even shorter.

Mr. SYMINGTON. Are these of such minimal importance, or do they show a decreasing likelihood as the flight endures to the point where it would become no longer a factor, in your judgment?

Dr. BERRY. I think, as far as their magnitude is concerned, to date, they have not been of a magnitude where they have caused any difficulty with performance as far as a crewman is concerned, nor would he be aware of any of these effects were we not using techniques to elicit them.

For instance, in investigating the cardiovascular deconditioning, we have used a tilt-table in Gemini and in Apollo we are using lower body negative pressure to elicit this response. If you ask the man whether he has any symptoms, how he feels postflight, or do a normal examination, you would not find any evidence of any change here. You have to elicit these changes the same as if you want to look at calcium or the exercise capacity. He is not aware of the loss of exercise capacity unless we test him on a bicycle ergometer to a maximum performance level.

It is our belief, at the moment, that these changes will plateau out and that they will not continue. We don't know that for a fact, however; it is a feeling and we have to have the facts. It is important to get longer duration data.

Mr. SYMINGTON. Mr. Chairman, I just would like to suggest that somehow these two contending points of view on the importance of gravity environment to man be thrashed out to the point where most reasonable scientific men would agree on the conclusion that this committee is being asked to accept. Last week, we were told that the gravity environment was important to all animals, including man, and we had this demonstrated in a lively fashion by one of the witnesses, describing the movement of fluids through the body when asleep, when awake, on the feet, and so forth, none of which occurs precisely in a weightless state.

It seems to me as if the witnesses today are not as nearly concerned, if indeed at all concerned, about this, at least insofar as the projection of the manned space flight program as of this date is concerned.

Thank you very much.

Mr. KARTH. Thank you, Mr. Symington.

Mr. Pettis.

Mr. PETTIS. Mr. Chairman, Mr. Symington has asked a question I was going to ask, but I would like to carry it one step further and ask either Dr. Berry or General Humphreys this question:

Is it possible that on longer flights man would adapt so well that it would be impossible for him to readapt in this sudden reentry?

General HUMPHREYS. I question whether it would be impossible for him to readapt or be readapted, sir. I think we mentioned that we have certain devices that we are looking at and hope to test, such

as the lower body negative pressure device, which really, in some ways, duplicates the effect of gravity on the column of blood.

In addition, we are looking at devices which are, if you like, total body exercisers, which do put dynamic stresses on bones, muscles, et cetera. Such devices perhaps will, if we need them, provide the re-adaption mechanism toward the gravity environment, and we are not so optimistic or so convinced that we are not worrying about it. We are looking at methodologies of overcoming this reaccommodation to the gravity fields, and this is part of our research program.

Dr. BERRY. I think we have seen change, Mr. Pettis, so that it would be possible certainly that you could have a man come back from a longer period of time and have some symptoms. It is conceivable. If that happened, then I think we would certainly do as General Humphreys says. We are looking ahead for that eventually. Should that happen, we would like to have some protective measures, and I think that is the worst thing that could happen, that we would have to provide him with some protective measures to help him through the readaptive period.

General HUMPHREYS. You might say we are qualifying the environment, rather than the man. I don't think we are going to change man significantly because it takes many generations to do it, and what I think we are talking about is qualifying the environment in which man can effectively and safely work and live and the environment covers a great many factors, not only the gaseous atmosphere and his food and his water and the weightless effect and the change in rhythms and all these things, but we need to qualify the environment in which man works best and has the best opportunity to be effective while he is flying and effective when he comes back, and I think this is the main function.

Mr. PETTIS. One further question, Mr. Chairman. I think that I see in the joint testimony the suggestion from a philosophical standpoint that space flight might, after a time of adaption, be easier on man than earth living?

Dr. BERRY. I think that is a possibility for the weightless environment. You can't say it about the space environment overall. Obviously, if you exposed man to the space environment of vacuum, he can't live. But if we are talking about the weightless factor alone, that is a less demanding environment, in a sense, on his physiology. It requires adjustments of his physiology, and determining how those adjustments work for the longer period of time is the research that is necessary. That is why it is necessary to have a space station so that we can see what happens to the time course of these events. We have not been able to do this in flight yet.

What we have been measuring is what happens to the man's status before the flight, and basically after the flight, with the exception of some of the experimental data, we were able to obtain on the 8- and 14-day flights where we did get a fair amount of in-flight measurement in a very cramped small spacecraft.

I think we need to look at this time course in some detail; how do these changes develop over a period of time, and then what happens to him actually in flight without looking at the man just before and after the mission. That is what we hope to get from both the Apollo Applications program and the space station program.

Mr. PETTIS. I had one other question, but there are other committeemen.

Mr. KARTH. We have more time than anything else.

Mr. PETTIS. Both of you men are physicians. I wonder if you have seen, in this program, any possibility of the weightless state being medically helpful to people other than astronauts?

General HUMPHREYS. I guess if we could produce a weightless state without the stresses of getting there and getting back; yes, there are certain pretty obvious things such as somebody with congestive heart failure or with very bad varicose veins or hemorrhoids. You could reduce the pull of gravity and one can sit and think of a number of conditions that might be helped by this. But I think certainly in the context of the next decade or two or three, getting there and getting back would be more stressful than staying at 1 g., sir.

Mr. PETTIS. Thank you.

Mr. KARTH. Mr. Koch.

Mr. KOCH. Mr. Chairman.

General, what is interesting to me is this—I find that there is a discrepancy, or difference of opinion is the better way of putting it, between the statements made this morning, and those made by Dr. Reynolds and Dr. Adey, with respect to the importance of the experiment with the monkey. It doesn't surprise me, because I have never been in a trial where, in a medical situation, you couldn't find two doctors to testify adverse to one another. So that is really what we are seeing this morning. [Laughter.]

What is interesting to me, though, is this, that you come to the conclusion that the monkey experiment is, in your mind, scientifically interesting—I am not quoting you—but you really do not consider it vital to what we are doing.

Mr. KARTH. Laudable was the word.

Mr. KOCH. But not vital. It is scientifically interesting, laudable, but not vital; and yet you talked, both of you talked, about the fact that you are going to look at the data from the manned space flight of 28 days before you go into the next project, 56 days, and you also indicated that the data, which has been given to you with respect to the monkey, in your language, is preliminary data. That was, I think, the general's statement.

If it is preliminary, and if, as we have been told, you are not going to have all the data until January—that is what we were told—why isn't it worthwhile to wait until you have not only the preliminary data but all of the data before you proceed with the manned venture?

General HUMPHREYS. We are going to proceed with the manned venture about 1972, sir, and we are talking about this data being available to us in January 1970. If this data is, in fact, in its final form, so convincing, I think we can have a look-see at what we are going to do to protect man more than we are, although I don't think it will be necessary.

Second, I don't believe that we can really accept the data as being necessary, because we know a fair amount about man and, as I said before, this data confirmed some of the things we know are occurring in man, although not with the severity and not with the progression.

I think there are many reasons why they are different, and, therefore, I just can't say this should stop everything right now, because it is only one data point and one experiment on one subject.

Mr. KOCH. So that we don't get involved in semantics, which happened the other day, when I ask you about gross physical adverse effects, that relates to a standard in medical terminology. You have a standard and you equate that standard against what might occur, and at some point it becomes gross with respect to its adverse effects. That is a fair statement?

General HUMPHREYS. Yes, sir.

Mr. KOCH. You say with reasonable medical certainty there would not be gross adverse medical effects upon man as a result of the 28-day flight, based upon the information currently available to you?

General HUMPHREYS. I cannot unequivocably say there will not be, but I can state I don't think there will be.

Mr. KOCH. It is not a question of what you think, nor am I asking you to state beyond peradventure what will occur, but a reasonable question always placed to medical people in any situation where you are seeking their advice is, can you state with reasonable medical certainty—those are the three magic words, reasonable medical certainty—that there would not be any gross adverse physical defects upon man in this 28-day flight, based upon the information you currently have?

General HUMPHREYS. Yes, sir; I think based on the information we currently have and our understanding of man, I would be willing to state it is my opinion that there will be no gross adverse medical effects.

Dr. BERRY. I would certainly do that, too.

Mr. KARTH. Is the gentleman satisfied he did not get another opinion, rather than what he was attempting to get?

Mr. KOCH. We are not sparring. We are trying to get the facts on the table. You have included in your response, based on reasonable medical certainty, that you have come to this conclusion.

Isn't that a fair statement?

General HUMPHREYS. That is correct.

Dr. BERRY. That is a fair statement.

Mr. KOCH. No other questions.

Mr. KARTH. Mr. Taylor.

Mr. TAYLOR. Have you reached conclusions as to the effect of reduced pull of gravity, or in some cases of gravity, on such things as the heart beat, blood circulation, and other fundamental body functions?

Dr. BERRY. Yes, sir. We have. The information that we have to date shows changes that have involved certain body systems with exposures that have been of varying lengths. As you know, in our flights to date, we have had eight 4-day flights; we have had four 8-day flights; and we have had two 11-day flights; and we have had one 14-day flight.

Now, from this gamut of information, it is very obvious that we are seeing some effect on the cardiovascular system, and we feel you do have some redistribution of blood volume in a weightless state. We have seen some loss of plasma volume in the immediate postflight determinations, some change in electrolyte balance, and some changes in heart rate.

We have seen no effect on man's capability to do the task in the weightless environment. In short, if you call upon the cardiovascular system to respond to a task, from all the information at our disposal

at the moment, it appears it responds in much the same way that it does here to do that particular task.

We do see some slowing of rate during the prolonged weightless period; but when you stimulate man, you get proper increases in rate at that time. We have, as you know, seen change in other systems. We have seen evidence of change involved in the musculoskeletal system, there has been some loss of muscle nitrogen and some loss of exercise capacity that is short lived. It lasts for normally 24 to 48 hours postflight before return to normal. There has been some minimal calcium loss from bones also, and I think that is in summary pretty well the kinds of things we have seen. We have tried to scan the system, and as we can see some evidence of change in those systems, then we home in on those particular changes.

Mr. TAYLOR. Have you seen danger to human life or physical safety?

Dr. BERRY. No, sir.

Mr. TAYLOR. We are all familiar with the experiment with the monkey which has been referred to. What other space experiments have you made with animals?

Dr. BERRY. Well, that is not really in my area. The people in the space sciences, Dr. Reynolds and his people, should talk about that; but within the maned flight program, very early, prior to the first manned flights, there were two animal flights.

There was an animal flight that was before the first suborbital mission, and there was an animal flight in orbit before the first orbit mission, and those are the only animals within the manned flight program.

There have been other types of things flown within the biosatellite program.

Mr. TAYLOR. Have you had any other unfavorable results, such as the monkey case?

Dr. BERRY. I don't know of any. I haven't seen anything that would certainly cause us any concern.

Mr. TAYLOR. Now, if you know, what future experiments of this type are planned?

General HUMPHREYS. Sir, at the moment there are certain flights, certain animal or tissue flights, that are planned on the Apollo Application program: two on circadian rhythms of animal species, plus an experiment on human cell cultures in zero gravity. At least I don't—and I speak for myself only—find anything wrong. As a matter of fact, I support the use of animals in a space laboratory, biomedical, biological laboratory. I support them for looking at long duration subtle effects, and I frankly would be very happy to see an animal flying for a long time in a laboratory environment or appropriate animals for the thing you want to study flying in a long-term space laboratory with man being a part of the laboratory just as he is on earth. I would like very much to see that because I think animals could stay and man doesn't want to stay too long anyway. He wants to come home to his family occasionally even if he is an explorer, but we don't treat the animal as well, or we can take his family with him.

We would like to see many things happening with animals in a space laboratory. We would like to see it well done and put in that perspective.

Mr. TAYLOR. That is all.

Mr. KARTH. Are you saying, General, that in your judgment the significance of those kinds of experiments would have little or no bearing upon the prolonged effects of weightlessness upon man?

General HUMPHREYS. No, sir, I am not saying that at all. I am saying through animals we can investigate mechanisms which we cannot reasonably investigate in man today.

Mr. KARTH. You have said, have you not, there is no real meaningful or significant information that we have gained from the biosatellites that can be extrapolated into what the effects of prolonged weightlessness will be on man? You have said that, haven't you?

General HUMPHREYS. Yes, sir.

Mr. KARTH. Dr. Reynolds of NASA is here again today. Do you agree with that statement, Dr. Reynolds?

Dr. REYNOLDS. The latter part of your statement about direct extrapolation of this monkey data to man leads me to agree with General Humphreys that you cannot extrapolate this kind of data directly to man. I do believe, as General Humphreys mentioned in his testimony, that the confirmation of the occurrence of the Henry-Gauer reflex which was proposed as a likely explanation of some of the events we have seen in man is a useful—in fact, I think I used the word "crucial" in my testimony the other day—experimental validation of theory.

Mr. KARTH. You agree with that?

General HUMPHREYS. I think the data is useful.

Mr. KARTH. As far as you are concerned, General, you feel we have not gained more valuable biological data or information on all of our biosatellite flights to date and what effect or what value that data might have on prolonged weightlessness as it concerns man than we have received from the manned flights we already made. Is that correct?

General HUMPHREYS. Sir, I do not believe we have received more valuable data on the biosatellite flights to date than we have on the manned flights to date. I think the data from the biosatellite flights has been good data. I think the purposes of the biosatellite experiments were specific, and I think that information must be collated and correlated according to what the experiment was designed to do.

Mr. KARTH. What is your answer to my question, Dr. Reynolds?

Dr. REYNOLDS. I am not sure I can remember the exact complexion of your question, but if I understand it properly, it was whether or not more valuable scientific data had been obtained from the biosatellite flights to date than the manned flights to date.

Mr. KARTH. Biological, scientific data.

Dr. REYNOLDS. The observations carried on in the manned flight program have been medical observations, not experiments in the formal sense of the word. The interpretation of these observations has lead to certain experiments that can be designed from them, and I think it is very valuable data. It is not experimental data of the type that was obtained in Biosatellite III. I don't believe one can make an exact comparison between these.

Mr. KARTH. Getting back to the other question I asked, I guess it really related to extrapolation. The record that we are making on this whole subject, is going to be with us a long time, and I assume somebody is going to be proven wrong.

I asked that question of several witnesses last week. This was in reference, General, to the statement that Dr. Berry was quoted as having made in U.S. News & World Report in answer to the question about extrapolation. His answer was, "Any extrapolation from the event"—that is, Biosatellite III—"to future manned space flight is simply unjustifiable speculation." That is also your statement, isn't it?

General HUMPHREYS. It was very close to it, sir.

Mr. KARTH. I quoted that, quote, unquote. Is that also your statement?

General HUMPHREYS. I think, as I said, it is very close. I don't remember exactly my words to the man who talked to me on the phone, but I think I can agree with that.

Mr. KARTH. I asked Dr. Adey if he could agree and he said, "No, sir." I asked Dr. Pace if he would agree with that and he said, "No, sir." And I asked Dr. Meehan if he would agree with it and he said, "No, sir." The only reason I think I reiterate this is to make sure the record very clearly shows this disagreement which is very fundamental, and, I think, a very important disagreement between professionals in the medical community.

The chairman asked whether or not there was any cooperation between the Air Force and NASA on this whole question of prolonged weightlessness and what experiments we ought to conduct and how we ought to conduct the program, and your answer was, "Yes, there has been some coordinated effort."

General HUMPHREYS. Quite a bit, sir.

Mr. KARTH. Has the Air Force offered any recommendations or suggestions that NASA has chosen not to accept?

General HUMPHREYS. In the field of biomedicine, I don't believe there has been an experiment offered that we have not considered together and accepted. As a matter of fact, some of the experimental hardware which we are talking about in the Apollo Applications program really had its beginnings in the Air Force.

Mr. KARTH. In times past, General, up to this point, has the Air Force indicated they would rather we do some other things first, before we did what we have in fact done?

General HUMPHREYS. In my 2½ years, this has not occurred. We have, as I said, committees that look at things and they consist of both Air Force and NASA medical people. And I don't recall any time in the past 2½ years when the Air Force has said "We want to do this" and we have said "No."

Mr. KARTH. Dr. Berry says we do not have evidence that we need artificial gravity for long duration spaceflight—for example, a 2-year mission to Mars. The fact of the matter is we don't have any data, do we, Doctor, pro or con, as to whether or not long-duration space flight of this character would be harmful, permanently or otherwise damaging to the individual?

Dr. BERRY. That is correct, Mr. Karth, in that we have no data for periods of time as long as 2 years. We cannot extrapolate the data we have at the present time. As you well know, we have only data for 14 days and that is the longest period of time man has been exposed thus far.

Mr. KARTH. Because this is a very serious question and because there really is no data to confirm or deny that there would be any lasting

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effects, any long-term effects, any damaging effects, I would assume you would agree, therefore, as a professional medical man, that it would be somewhat senseless at this point in time—unless money is no object—to spend substantial sums to develop such a system prior to having this information.

Dr. BERRY. No, sir; I don't think I would agree with that exactly the way it is stated.

Mr. KARTH. Tell me how you would state it.

Dr. BERRY. I say my belief is the only way we are going to get the information that is necessary in order to go ahead to build the systems that are necessary to explore space is to expose man for longer periods of time in a laboratory situation, and this means that we need a space station to get that kind of information.

Mr. KARTH. I don't think there is any disagrement on that point either between you or this committee, or for that matter any of the witnesses that appeared last week. I doubt if there is any disagreement on that.

My question was, Should we spend substantial amounts of money developing hardware, not knowing the answer to this question, the question as to the effects on the 28-day flight or the 56-day flight as it relates to a 2-year flight?

Dr. BERRY. It would be my opinion—and I gather what we are trying to do in the agency is to go in a stepwise fashion—that you are going to build this hardware in a stepwise fashion and, of course, the first hardware being put out at the present time is AAP hardware to get this information for 28 and 56 days.

As we look ahead, the next step would be having a space station capability where you could have a larger volume and have this capability for looking at varying levels of g. and to expand this information, and that is the kind of information that is, I think, going to be necessary in order to allow us then to go ahead for the long 2-year kind of flight; and I think that information is absolutely necessary.

I do not think we can extrapolate from what we know now. As I have said, I have some feelings about that, but certainly I would not commit anyone based upon feeling. We want data.

Mr. KARTH. The question was asked, I think, of you, General, by Mr. Koch, when he said, since we will not have all of the information from Biosatellite III until Janary 1970, what is the rush that we get into the longer duration manned space flight at this time? Your answer was that we are not going to be doing that until 1972. After all, January of 1970 is considerably prior to that time.

Really, what we are talking about here as well as the Mars venture is what about the costs that are associated with it, the development and all the work being done, the putting together of the project in an engineering sense, when it might well be we are going to have to back up and reengineer, back up and redevelop, back up even further perhaps and even redesign. That is really the question, and you feel the country is wealthy enough or whatever the reasons might be, that we should take these chances, that we should go ahead and develop hoping there will be no problem; and unfortunately, if there is, we will just have to back up and do it over. You feel it is worth the gamble?

General HUMPHREYS. Yes, sir; I do.

Mr. KARTH. You feel it is more appropriate to do that, General, than it is to do more exhaustive, in-depth, and meaningful research in the bioscience area prior to entering into these expensive development areas?

General HUMPHREYS. You put me on a difficult spot. I think it is of extreme importance to do extensive biomedical research testing. I am hopeful that the program will allow us to do these things. I do not believe we can ever do the ultimate stages of research related to man in the space environment, the weightless environment, without being in space weightless. Therefore, we must have some sort of system in which we can test our hypothesis developed on the ground.

Mr. KARTH. I agree with you.

On page 6, however, in your statement you said, and it is the last sentence:

> Second, this program is but the beginning of an in-depth study on man in the space environment.

Don't you think we should have begun that a long time ago, really?

General HUMPHREYS. Yes, sir. I think we have begun, but we have been unable because of the constraints of the missions—and let us be very clear that the missions in the past were, with a few exceptions in Gemini, were operational in nature and not primarily or specifically aimed at doing biomedical research on man and on animal.

I think that the Apollo Applications program to which I was addressing myself in that statement is a program which has a specific objective of finding out about man, and it really is the first one which will allow us because of the constraints of the hardware and the planning and design and so forth to really look in depth at man, and I must admit we have not been able to do in-flight studies on man in depth in the programs to date.

Mr. KARTH. And why haven't we been able to?

General HUMPHREYS. I don't think they were the primary objectives of the program, sir.

Mr. KARTH. I recognize the primary objective of the Apollo program was to land a man on the moon and get him back alive. However, in addition to the engineering requirements to do that—that is, by building fail-safe boosters and fail-safe Apollo spacecraft and a fail-safe LEM—the question about whether or not man would be able to sustain these variations had not really been answered up to that point. So it seems to me that we might well have done some of this work we are now talking about which, indeed, is laudable, but which I think is late. We may well have done some of this work prior to this time, wouldn't you agree wit that?

General HUMPHREYS. I think we have done some.

Mr. KARTH. More than what we have done?

General HUMPHREYS. I would like to have seen more done; however, we did fly man very safely for periods exceeding those flight durations for lunar exploration on Apollo. We did test man in the Gemini series and in flight durations to exceed it. So I think we proceeded into Apollo with a considerable amount of confidence.

Mr. KARTH. Your point is really that man, for all practical purposes, is going to be the test animal, right?

General HUMPHREYS. I think in the final definition man is the test animal. Much can be learned in other studies, but man in the final definition will be the test of what man can do.

Mr. KARTH. You are not saying the use of primates, for example, and I don't want to go all the way to elephants like my colleague from Missouri suggested we might——

Mr. PETTIS. Substitute a donkey. It would be a little cheaper. [Laughter.]

Mr. KARTH. Leave that in the record, I think.

The point you are making really is that you don't feel there are meaningful, significant, or any extrapolations we might be able to use by conducting these kinds of tests on primates?

General HUMPHREYS. No, sir; your choice of the word "any" makes my answer, "I do not agree." I think there are very definite pieces of information that can be obtained, and correlations, from appropriate animals, primates, or pigs, for example. Pigskin is much like human skin. We would say, yes, there is a great deal to be learned from experiments on animals, and I think that the answer that I have to give is just that, that there is a great deal to learn from animals.

Mr. KARTH. But we don't have any animals in the program at this point, even pigs.

General HUMPHREYS. I guess we have some vinegar gnats and pocket mice and human tissue cells in the program at the moment.

Mr. KARTH. But we don't have animals.

General HUMPHREYS. A pocket mouse is an animal.

Mr. KARTH. Like pigs. Is that the 28-day flight?

General HUMPHREYS. That is on the program; yes, sir.

Mr. KARTH. Is that animal sufficiently huge and does it have the constitution and wherewithal, I suppose, to undertake some of these implantations that are probably required or that we would want to do on animals?

General HUMPHREYS. The purpose of that experiment is to study circadian rhythms and since this is Dr. Reynolds' experiment, I would rather have him describe it since I am not totally familiar with all the details.

Mr. KARTH. That appears to be one of the problems, I think. We are frankly not quite as familiar with what the other person's experiment is or his objectives are as we might well be. As a result of that we are prone to formulate some biases, and the chairman not excluded in that regard.

But nonetheless, as far as you know, there are no plans to conduct similar type experiments as we conducted on Biosatellite III on the 28-day and on the 56-day flights?

General HUMPHREYS. There are at the moment no plans to conduct a similar experiment to Biosatellite III on the 28-day or the 56-day flights as we see them in AAP. It is being discussed, but there is certainly not an approved program to do this.

Mr. KARTH. There are no other programs to do this, are there, to your knowledge?

General HUMPHREYS. No, sir; as I understand it, the agency does not plan to fly a repeat of Biosatellite III.

Mr. KARTH. The artificial gravity problems, General, that have been alluded to and as you said are major problems, they might prove to be

as great as long-duration weightless flight itself. Is this an accurate statement?

General HUMPHREYS. I think that is a very reasonable statement. I think that is why we are looking at two directions to go: One is artificial gravity and one is other supportive or preventive means. We are not attempting to go one route or the other.

Mr. KARTH. What are the other supportive or preventive means?

General HUMPHREYS. I mentioned in my statement the lower body negative pressure device which in part duplicates the hydrostatic pressure due to gravity, but there is also an exercise system which the Air Force is working on, sir, at the moment, an attempt to develop a flight system which will give one a total body exercise capability which will put the dynamic stresses on bones and muscles that are needed to replace the effect of man walking upright in gravity.

Mr. SYMINGTON. Mr. Chairman, can I interrupt?

Mr. KARTH. Yes, indeed, Mr. Symington.

Mr. SYMINGTON. One thing about gravity is that it is there whether we are exercising or not; and if it is exercising a beneficial effect on us, it is nothing we, by our own will, have to achieve. But for long periods in space, to require a person at a certain time of the day, every day, to take certain exercise is placing the kinds of strains on him which are unusual for man and which here on earth he generally doesn't accept.

You feel as a psychological phenomenon there would be no trouble with the requirement that the astronauts, in order to achieve the beneficial effects of gravity, perform daily routine exercise on a trip to Mars and back?

General HUMPHREYS. I think the flightcrews today have pretty much such a routine of exercise keeping them in physical fitness, and I think exploration crews would be somewhat of the same breed of cat, who believe in this and believe in it fully.

Mr. SYMINGTON. Because Dr. Berry had said in effect weightlessness might be easier on man, but here you are requiring man to do something to overcome the possibly deleterious effects of weightlessness.

General HUMPHREYS. We are talking primarily about the transition to a gravity field again.

Mr. SYMINGTON. I wasn't.

General HUMPHREYS. I was. These are protective devices primarily for that purpose.

Dr. BERRY. I think what he is saying is you do not necessarily need this exercise in the weightless state to keep you capable of performing in the weightless state. Where that decrement may show up is when you come back to the 1-g. environment.

Mr. SYMINGTON. In other words, we are only concerned about the exercise of 2 years just for that last 24 hours of reentry?

General HUMPHREYS. I don't know about the 2 years. I don't think we know that answer. That is something we have to learn about.

Mr. SYMINGTON. When does your certainty begin to turn to doubt in terms of duration—28 days? 56 days? 100 days? Can you sort of calibrate that for us or indicate when you would begin to want to know? For example, if you could send up a monkey with none of the constraints that are referred to in paragraph 3 of page 2, so he could in

fact not be restrained, nor invaded by multiple instrumentation and could be fed in some fashion periodically through ground impulses to the craft, would you think it would be a valuable thing to try such an extensive flight out on a primate or other animal? Or would it be your decision just to continue to extend man's flight by doubling its time until you discern something wrong in the man?

General HUMPHREYS. I think there are several things I would like to answer in that one. One, I have already stated that I believe it would be valuable to concurrently fly animals and allow them to remain in the space-flight environment longer, continuously, as man goes and comes, to determine subtle effects on the animal.

Secondly, the doubling philosophy, I guess, I subscribe to for short durations, say, 28 days above 14, but as one goes out further, I am not at all convinced this is the philosophy that needs to be or should be followed.

Thirdly, I don't think I would want to put a man up for 2 years at this point in time, and I would rather go at him step by step and understand him at specific time phase periods and understand the environment we must provide for him.

Mr. SYMINGTON. You say you wouldn't subscribe to the doubling theory. I take it what you mean by that is at some point you might be willing to quadruple his experience in space.

General HUMPHREYS. I might, sir, depending on what I find as we go downstream.

Mr. SYMINGTON. You could arrive at these determinations without benefit of the biosatellite, bioscientific information you would derive from primate or other animals in space?

General HUMPHREYS. I think it is possible, but I think our information base would be greater if we have appropriate animal subjects properly instrumented, properly observed, and manipulated just as they are in an earth laboratory. It would enhance our base of information.

Mr. SYMINGTON. That brings me to this question. When the chairman asked first you and then Dr. Reynolds as to whether or not you gained more bioscientific information from manned flight than from the monkey's experience, you said, yes, the monkey gave you less. Then Dr. Reynold's said, well, perhaps we are talking about different things; one is the monkey was an experiment and the manned flight was more an anecdotal diagnosis. At least that was the expression used last week.

Now you are saying as you probe deeper into space for longer periods you think there might be more value to the experimentation on the primate than you have seen so far.

General HUMPHREYS. No, sir; I don't think I said that, and as I recall—I may be wrong—I thought the chairman mentioned information applicable to man; and if that phrase is there, I think my answer was correct.

Mr. SYMINGTON. I would leave it in there, certainly.

General HUMPHREYS. We have gotten more information applicable to man from our spaceflights than we have from the biosatellite flights.

Mr. SYMINGTON. More bioscientific information applicable to man?

General HUMPHREYS. Yes; I think I stand with that statement. I do

not really say we must use animals. I say that we can use animals if we find deleterious effects. We can use animals to understand mechanisms which we do not at this point in time understand until we develop means of instrumentation which man will accept. We can use animals to understand mechanisms which we cannot do in man. Up to now we do not feel we have found any significant deleterious effect.

Mr. SYMINGTON. But a little bit back there in your testimony you indicated that for peace of mind regarding longer flights of man you would like to have some type of scientific information from animals. You are now saying you are not sure you must have it. You would like to have it.

General HUMPHREYS. Yes, sir; I would like the opportunity to use animals as we require them. That is what I am saying.

Mr. SYMINGTON. But if you reach a certain level in the manned flight which causes you concern about the fate of man on a longer flight, where will you turn to get the information you would need? You would then want to send an animal up for a longer time, or do you continue to believe that would not be necessarily relevant to man's experience?

General HUMPHREYS. I guess I must go back again, sir, and state that if we can determine the mechanism with man of whatever deleterious effect we have seen and devise a protective means, then we would not necessarily have to have an animal. But if it is in a system we cannot properly monitor in man, then I think we must go to the animal for the answers; and this is a traditional way of doing biomedical research, I think.

Mr. KARTH. If the gentleman would pardon an interruption.

Of course, that is true, General, isn't it? We have done so much experimentation on animals in the laboratory that have been worth while, meaningful, and given us irrefutable evidence as we extrapolate those experiences to the welfare and well-being of man, haven't we?

General HUMPHREYS. Yes, we have done a great deal.

Mr. KARTH. In this instance you do not feel the extrapolation means a thing.

General HUMPHREYS. That is not what I said.

Mr. KARTH. In answer to one of my previous questions, the extrapolation from Bonnie to the well-being of man under prolonged weightless conditions cannot be made. There cannot be an extrapolation.

General HUMPHREYS. I do not think there can be a direct extrapolation to man.

Mr. KARTH. Our whole history of research with animals and the extrapolation, our whole medical experience is preponderate and has been good in that regard, isn't that true?

General HUMPHREYS. Yes, sir; we have one thing here, though. I think we keep on forgetting, it seems to me, and that is we have one experiment on one subject, and I guess from this basis I don't think you can directly extrapolate all these things to man.

Mr. KARTH. Well, I think you are equivocating a little bit, General, if you don't mind my saying so. I think I can agree we can't extrapolate all of these things that occurred on the monkey. But all of these things do not mean we can't extrapolate on some of these things, and at least draw some conclusions that have some sound bases in medical science.

General HUMPHREYS. Yes, sir; I think that is right. For example, the so-called Henry-Gauer reflex, the pressure receptor in the right side of the heart, apparently this has been shown and demonstrated in this animal, and I quite agree. This is a valid proof that this does happen in primates and we think it probably happens in man.

Mr. KARTH. There is a great deal of difference between the reactions of the primate flown, and the reactions of the primates from identical experiments that were conducted on the ground. You mentioned, for example, in your statement that certainly the animal was harassed with implantations. That is true; but so was he when that experiment was conducted on the ground. He was harassed by virtue of the fact of his immobility, but he was also harassed when that experiment was conducted on the ground. He was harassed by virtue of the fact he really didn't have complete control of everything he ate or everything he drank or when he wanted to and how much, but he was harassed to the same degree, as I understand it, on the ground.

The difference between the experiments was that one was conducted on the ground and the other one was conducted under weightless conditions. That was the difference. And there was significant difference in the reaction of the monkey and, indeed, in the final analysis in the health and welfare of the monkey between those same experiments that were conducted on the ground and those that were conducted in space under weightless conditions, were there not?

General HUMPHREYS. Yes, sir; conditions were similar but we know there are individual reactive differences within a species and until I can see detailed environmental and physiologic data on both animals and compare them, I cannot be absolutely sure there were no contributing differences. In fact, the investigators themselves state that further tests are planned to determine whether certain factors such as diet and the environmental parameters of temperature, airflow, and humidity may have sensitized the animal to weightlessness.

Mr. KARTH. Really, that is what we are talking about—the difference, you see, between the weightless condition of the monkey with the same experiments that were conducted on the monkey when he was not subjected to weightless conditions. But you still feel and you still maintain—what is not true, Doctor?

Dr. BERRY. I am not sure from anything that we know—the experimenter has to say this—but from anything that I know at the moment, I think it would be difficult and I think probably the experimenter would find it difficult to say that everything was exactly the same except weightlessness alone.

Mr. KARTH. The record pretty much proves that out.

Dr. BERRY. Can say that the degree of isolation as far as the animal was concerned and all this? If that is so——

Mr. KARTH. I can say my recollection—while no one has ever said it was superb—it is good enough on this particular thing we are talking about, the isolation matter, that Dr. Adey did testify for the record here that it was identical, and I think that is the word he used, "identical." If he didn't say exactly in all experiments, he did imply strongly they were duplicated to the best possible extent that human ingenuity could duplicate them. The record will bear that out.

Under the circumstances, I guess my question is that in spite of this, this one salient, if not only difference in the experiment on the pri-

mates, that weightlessness, you feel, cannot be extrapolated in any meaningful way whatsoever so as to come to any conclusions whatsoever as it applies to man?

General HUMPHREYS. No, sir; I don't believe we can extrapolate it to provide conclusions to man.

Mr. KARTH. I am sorry. I didn't quite hear you.

General HUMPHREYS. I don't believe we can extrapolate the data I have heard to a conclusion regarding man at this point in time.

Mr. KARTH. General, are you familiar with all the data we have now on Bonnie up to this point?

General HUMPHREYS. No, sir; only that which appeared in the briefing to Dr. Paine and the press conference.

Mr. KARTH. Aren't we talking to each other?

General HUMPHREYS. Yes, sir; I have what Dr. Reynolds had at the briefing and the press conference. We discussed it.

Mr. KARTH. Has there been any communication between you, Dr. Berry, or you, General, and Dr. Adey, who is one of NASA's principal experimenters?

General HUMPHREYS. Only a very short discussion the morning of the briefing and the press conference, sir, about this particular flight that has been flown.

Mr. KARTH. If there is a concern about this whole question of weightlessness, and I assume there is, isn't it rather unusual we haven't been talking to the principal experimenter in some length, in some depth, on a different number of occasions; or have we been too busy going about our own responsibilities which, I guess, are somewhat identical in this instance?

General HUMPHREYS. We have been talking to Dr. Adey. My staff have talked at length to Dr. Reynolds' staff. Dr. Adey is a member of a couple of committees that advise us. We have seen him on a number of occasions. I have not, as I said, been able to discuss the data per se of the biosatellite with Dr. Adey since the flight.

Mr. HAMMILL. Mr. Chairman, may I ask a question of Dr. Berry?

Mr. KARTH. Counsel, please.

Mr. HAMMILL. Dr. Berry, do you suppose that among all the manned space flights the one that is most comparable to the biosatellite flight would have been Gordon Cooper's flight in the MA-9?

Dr. BERRY. As to duration?

Mr. HAMMILL. And also under restraint, no exercise.

Dr. BERRY. MA-9. I am sorry. That was only about 30 hours, but for restraint, and so forth, I think you could probably say it was more similar.

Mr. HAMMILL. What was Dr. Minner's report? He was the physician that looked at Gordon Cooper when he came back. What did he have to say about Gordon Cooper's condition and was there anything comparable in your view to Cooper's condition on coming back to anything that was experienced in the monkey?

Dr. BERRY. I think Gordon Cooper as a result of that flight had some cardiovascular deconditioning which resulted in a near faint on the carrier deck when standing in the upright position immediately after getting out of the spacecraft. That, at that particular time, was confirmatory evidence of a thing we had seen on Wally Schirra's flight, the flight before, where we had seen evidence of pooling in

the lower extremities without any symptoms. We did see some pooling of blood in the lower extremities on Wally and this is why we had looked specifically in Gordon's case and planned to do tilt studies for the first time in the program, which we did on that flight. So we did see evidence of cardiovascular deconditioning at that time, and I am sure there was cardiovascular deconditioning involved as far as the monkey was concerned, probably.

Mr. HAMMILL. That was brought on first by this Henry-Gauer reflex in a state of weightlessness, was it not, and then the reentry caused the pooling of blood in the lower extremities?

Dr. BERRY. We are not totally sure about this thing. We feel that what is happening is that we get a shift of body fluids when the individual is weightless. We get a redistribution of blood volume where you normally have more blood volume in the lower part of the body when you are in 1 g. When you become weightless, you get an increase in pressure that is picked up by the pressure sensors in the atrium and this starts that reflex thing.

We have never been able to show that exactly in man, but from the data that has been obtained, and this is partially the data, it occurs in man. The one experiment where we were able to fully get urine volume data on man was the Gemini VII experience, the 14-day flight. We saw no real evidence of a diuresis in man where he was actually putting out more fluid than his intake. We did not see evidence of that in that one instance. Again, that is a single flight instance with two people.

So we feel that certainly what happens is when your cardiovascular system adjusts, the reflexes change. We feel there is probably some change in compliance in the vascular system that goes on; and when you then come back to the 1-g. environment, you have to readjust this and get the blood elevated.

There was grave concern about this prior to the 4-day Gemini flight. We had people who very seriously felt we were going to have the crewmen, as soon as they started to get into the raft from the spacecraft, fall in the water in a dead faint. We felt this was not going to be the case from some of the studies we had run with individuals in a ground-based experience. We felt that their cardiovascular systems were going to be handling this as has proven to be the case with all our experience thus far in Gemini and Apollo where we have had some cardiovascular deconditioning, but we have seen nothing in the systems as to any tendencies to faint or anything of this sort.

Mr. HAMMILL. The thrust of the testimony last week, by these three eminent physicians who had participated in the Biosatellite III experiment, was to the effect, if I recall it correctly, that the instrumentation on the manned space flights today was inadequate and unsatisfactory, almost nonexistent; and here in your statement today you say that the Apollo Applications program represents our first real opportunity to seriously investigate the effects of a weightless environment on man. Then on the following page you say: "This program is but the beginning of in-depth studies on man in a space environment."

But going back to page 3 of your statement, you say that the information that you have gotten from your manned space flights has

enormously outweighed the biosatellite information, and then you state the number of hours, and so forth, men have flown.

The essence of the testimony last week, I think, was to the effect that you really haven't gotten very much data at all, despite the fact we have been sending men up in space for almost a decade.

Dr. BERRY. I disagree with that thoroughly, and I think it depends on what you are talking about as data. If you mean reams of information on EEG or something of this sort, or central venous pressures and things of that sort, if you require that type of instrumentation, certainly that is true that we have not gotten that kind of data. I think the meaningful data here that we are trying to look at, though, is not what are the small changes in any of these particular things.

If you see some evidence of change, I think you want to go and look in depth into this area which is what we say we should do and you can go and start looking in depth at the mechanisms and then you have to instrument to do that sort of thing.

What we have tried to do in our program is look at the things that might be a problem, as far as man is concerned, that might cause any change in any one of his systems that we use any means we have but obviously we are not going to have implanted electrodes and we are not going to put catheters in the right atrium with man, although there are a lot of people who felt we should do that, but I think it is an impossible thing to do.

Mr. HAMMILL. The National Academy of Sciences, in its report, "Physiology in the Space Environment," under findings and recommendations, says: "We identify improvement of instrumentation and techniques for biomedical measurements and monitoring as a pressing need."

General HUMPHREYS. So do we.

Mr. HAMMILL (reading):

> Bioinstrumentation and telemetering devices presently available for manned space flights are, in our opinion, not adequate to obtain physiological data required for mission safety on long flights, quite apart from assembling data scientifically or operationally needed for the long term.

But really, I think the suggestion is, if we are going to do more in the future, why have you waited this long?

Dr. BERRY. We agree with you in that we do need more bioinstrumentation. We need bioinstrumentation that will allow us to get information without invading man, and we need a lot of work done in this area, and we have continually been pressing to get that kind of work done. We are, as a matter of fact—and I think it is important to realize even in the AAP program outline, we currently talked about this morning, 28 and 56 days—we are pressing the state of the art in instrumentation in that area without any question of a doubt. There is nothing we are going to use that we can go and buy off the shelf. We are still pressing in that area and, for instance, one of the best examples I can think of is to try and determine what the metabolic costs of this activity are, of doing activity in a weightless environment. It is vital we get good metabolic measurements in that situation.

We are using a lot of inferential methods even in the lunar surface activities. We have ways of getting at this, but to get accurate detailed measurements of the metabolic rate, you need a system that will allow you to get CO_2 and oxygen determinations on a breath-to-breath basis

in flight. We are trying to do that in flight models, and I think we will probably have it, but it is really pressing. It doesn't exist anywhere. We are pressing people to build and develop that kind of thing. It doesn't exist in the laboratory here on the ground.

Mr. KARTH. I think that is the complaint. I don't think the committee is saying that you are not pressing the state of the art. The fact of the matter is, we have pressed almost every state of art in the engineering and scientific world to get to the moon and back.

Dr. BERRY. That is correct.

Mr. KARTH. I think the question is, Have we spent enough on that facet of putting man in space and finding out whether or not he can really perform the duties and in the final analysis sustain no deleterious effects? That is the question. I think, for the record at least, I would like to have you provide precisely how much money we have spent out of the $25 billion we spent to go to the moon with man on this very question we are talking about.

Dr. BERRY. The thing you want for the record—you are not talking about bioinstrumentation, but you are talking about man overall, or just about bioinstrumentation, how much we spent on man in total or bioinstrumentation?

Mr. KARTH. Let's take both, and then we will be sure we cover the waterfront, but particularly I do want to know how much money we spent in this area as a part of the Apollo program.

(The information requested follows:)

Of the Apollo costs of $21.3 billion through July 31, 1969, $38 million were spent for biomedical purposes. Included in that total are costs of $9.4 million for the development and procurement of bioinstrumentation.

Then, No. 2, I would like to have you supply for the record, as quickly as you can so that we can write a report as quickly as we can, precisely what experiments we have conducted on the astronauts insofar as it relates to his well being and his ability to do the job and our ability to bring him back safe and sound and whole, and the results of those experiments—if you would provide that for the record, please.

Dr. BERRY. Be very glad to.

(Information requested follows:)

The attached table contains a list of formally assigned medical experiments by title conducted in the manned space program to date. In addition to formally assigned medical experiments, certain operational medical procedures are established and approved in support of each flight. The data derived from these procedures are used for the purpose of evaluating the well being of the flight crew and to further the understanding of biomedical changes incident to space flight and to insure that such changes as occur are detected, understood and documented. In addition, evaluation of such data are used for the realistic planning of subsequent flight missions.

Operational procedures include measurements conducted during flight for the purpose of monitoring the crews physiologic status in real time. Additionally, included in this category of measurements are the detailed pre-flight and post-flight physical examinations which include Immuno-Hematology, Clinical Chemistry and Microbiology evaluations.

While negative as well as positive findings are of interest, for the purpose of clarity and brevity, the former are not presented in the reference table. They may be found however in the "Supplemental Information" furnished with the statement of General Humphreys and Dr. Berry. Details of the medical procedures used and the results have been widely reported. A selected list of pertinent references are included with the table.

Flight mission medical experiment, measurement or procedure	Body system	Positive observation or finding
M 006 Bone demineralization M 007 Calcium balance Operational procedures	Musculoskeletal	Postlanding: 1. Minimal loss of bone density. 2. Minimal loss of muscle tissue. 3. Reduced exercise capacity.
M 005 Bioassays body fluids	Endocrine	Postlanding: 1. Apparent depression of stress hormones, during flight. 2. Elevation of stress hormones, postflight.
Operational procedures	Eye, nose, throat, skin, body mass.	Postlanding: 1. Eye irritation. 2. Nasal stuffiness. 3. Throat hoarseness. 4. Skin dryness, dandruff. 5. Moderate loss of body weight.
M 001 Cardiovascular reflex M 003 Inflight exerciser M 004 Inflight phonocardiogram Operational procedures	Cardiovascular	Postlanding: 1. Increased heart rate during launch, EVA, and reentry. 2. Short lasting increased heart rate. 3. Reduced tolerance to changes in posture. 4. Reduced exercise capacity.
M 011 Cytogenetic blood studies Operational procedures	Blood	Postlanding: 1. Moderate loss of blood volume. 2. Minimal loss of plasma volume. 3. Decreased red cell mass. 4. Increased white cell count.
M 008 Inflight sleep analysis (EEG) M 009 Human otolith study Operational procedures	Central nervous	Postlanding: 1. Sleep problems. 2. Inflight illness.
Operational procedures	Respiratory	Postflight: Some reduction in vital capacity.

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Mr. KARTH. Mr. Symington.

Mr. SYMINGTON. Mr. Chairman.

General Humphreys, I think you indicated, did you not, sir, that the report on the monkey's flight you received during the press conference with Dr. Adey, that was your first opportunity to examine the information from that flight?

General HUMPHREYS. Yes, sir.

Mr. SYMINGTON. When was that press conference?

General HUMPHREYS. I don't remember the date exactly, sir. About 3 weeks ago, I think, sir.

Mr. SYMINGTON. Do I take it that the press conference was as extensive as a briefing would have been in every respect, that you were satisfied you learned as much from the press conference as Dr. Adey had to say? Were you asking the questions, or were the reporters asking them, or how did this come about?

General HUMPHREYS. I did not really attend the press conference. I attended the morning briefing to NASA management before the press conference, and I heard Dr. Adey, actually, Dr. Naugle, Dr. Reynolds, Dr. Adey, Dr. Pace and Dr. Meehan and Dr. Pauline Mack all make a briefing of their findings, and I do have a copy of the visual charts they presented at that meeting.

Mr. SYMINGTON. And that took what, an hour or so of your time?

General HUMPHREYS. No, sir; it took about, as I recall, on the order of two and a half to three.

Mr. SYMINGTON. What concerns me, Mr. Chairman, is that there has not been enough communication between the people that are involved in the biosatellite program and those involved in the manned space program. The American people think we have one space program, not one for monkeys and one for man, and that there is a constant exchange of information and a close working relationship.

A briefing is different from a press conference. First, you said it was a press conference, and then you said it was a briefing. So if there is self deception on your part—and I don't think it is deliberate—I would have thought, to go one step further, you would have wanted to go into the lab and talk to the technicians. Whatever information you had as the basis for the testimony you have given us today you secured on this particular occasion from the press conference preceded by a briefing.

If that is how we learn from one another in the scientific community, I am surprised; but I guess I have been surprised by a lot of things, Mr. Chairman.

General HUMPHREYS. I guess, sir, that is all that was available. We had seen all that was available at the time they made their presentation. I spoke to Dr. Adey and Dr. Meehan for a few minutes after the meeting, before they left.

Mr. KARTH. You see, this is the concern that Mr. Symington and most everybody else here in Congress has. I would not doubt or hesitate to say, I think the American people have this concern. Are we really benefiting, you know, from the experiences we have undertaken as well as we might, or are we so busy going about our own business that we don't have time to back up and take five, if I may use that expression, to completely familiarize ourselves with what the effects of these space flights have been; and in this particular instance, Biosatellite III, and how possibly that might affect man in the future insofar as it relates to prolonged weightless conditions.

This is a thing that I think is concerning all of us. On the basis of what we have heard, I doubt seriously that this exchange of information has amounted to much. Let's get to know each other's problems and let's get to know, not just generally, but in a very fundamental way, the results of each other's experiments. Getting to know what they are, I think, is really a question, up to this point, that has not logistically or otherwise been made possible. I am a little concerned about it, and I think the Congress has a right to be, and certainly the American people do, because it is costing a great deal of money.

Mr. Koch.

Mr. KOCH. General Humphreys, in response to one of the questions about extrapolating from the monkey, you are very careful to say we could not extrapolate from this one monkey to man, and maybe that is true; but why isn't it reasonable to think you might make some reasonable extrapolations if you had 10 monkeys up there in various biospace projects? Isn't it possible? Isn't it perhaps true, with some degree of certainty, that you could get some information from that that would have a bearing upon what occurs to man?

General HUMPHREYS. I think the answer to that one can be stated this way, that we have been, throughout the history of biomedical research, doing specific studies on animals and in large enough quantity to extrapolate specific functions, not the total overall effect, but the specific mechanism, the function. I certainly believe you can extrapolate from animals to man within a limited framework, and there is no disagreement that you can.

Mr. KOCH. Is it your position—and I took this to be your position up to now—that further experiments on monkeys will not significantly assist you with respect to what you might expect to happen to man in future space projects, and in particular the 28-day one?

General HUMPHREYS. There are a lot of factors in that one, sir, but I must not be able to express myself adequately, because I feel very strongly that animal experimentation is of assistance.

Mr. KOCH. But not vital?

General HUMPHREYS. At this point in time, we do not consider a complete animal duplication of the 28-day flight vital.

Mr. KARTH. Would the gentleman yield?

Mr. KOCH. Yes.

Mr. KARTH. Would you consider it very helpful, useful?

General HUMPHREYS. It could be, sir, useful.

Mr. KOCH. You were very explicit, and I appreciate your candor with respect to my question about stating with reasonable medical certainty as to whether or not there would be any adverse gross effects upon man. You said there would not be. That was your opinion,

based on reasonable medical certainty. That question was asked of Dr. Adey, just to point it out to you, and I think you would be interested in his response.

My question to him, I think, was: Can you state, with reasonable medical certainty, there would not be gross adverse medical effects upon them? We were talking about men. Dr. Adey's response:

Sir, I think the level of incapacitation will be substantial in the inability to withstand the changes in reentry and immediately thereafter. This is one area where I would feel considerable concern. I would also be much concerned about the sleeping cycles and the ability of the man to perform well in consequence.

Would you say there is a difference of opinion between you and Dr. Adey on this subject?

General HUMPHREYS. There is no question about that. There is a difference of opinion between the two of us, sir.

Mr. KOCH. When you went to that press conference where you obtained the information, did you go there with a preconceived opinion that the biomedical information obtainable from that monkey would not be of vital concern in extrapolation to determine its effect upon man? Did you come with an open mind, or had you already formed an opinion on the subject?

General HUMPHREYS. I think I had a partial opinion, sir, because we had been hearing rumors about what had happened, and I knew how the experiment was put together, and I think I must admit I went with a preconceived opinion until I had seen this data.

Mr. KOCH. What was your preconceived opinion at the time?

General HUMPHREYS. That I doubted its validity as evidence which would indicate any immediate or sweeping change in the manned space flight program.

Mr. KOCH. Then you had a briefing which was part of a press conference, and it took about 3 hours in toto. Do you consider that kind of briefing, or press conference if you will, what ordinarily would be the general standards of professional communication in terms of discussing with a colleague biological experiments which have a bearing upon what you are going to do?

General HUMPHREYS. No, sir, and I fully intend to sit down as soon as the data becomes available and go over it in detail, and hopefully, with the investigators.

Mr. KOCH. That is good. You are telling us now you might change your mind after you have gotten all of the information. Isn't that what you just told us?

General HUMPHREYS. That my mind is open enough that if they can prove they are right, I will accept it.

Mr. KOCH. At this particular point, you have told us you don't have all the information.

General HUMPHREYS. That is correct.

Mr. KOCH. Yet, without having that information, you were willing to prejudge what we should do in terms of enormous expenditures of money, isn't that what you are doing?

General HUMPHREYS. No, sir.

Mr. KOCH. Tell me why not.

General HUMPHREYS. I am not basing my judgment about going on with the program simply on the biosatellite flight. That is only one factor in the process of sorting it out. I think my answer is, "No"; I would not base it that way.

Mr. KOCH. Would Dr. Adey's statement, which indicates he has a great concern about the level of incapacitation, put up some go slow warning to you?

General HUMPHREYS. Not to me.

Mr. KOCH. Why not?

General HUMPHREYS. It is Dr. Adey's statement, and it is also based on preliminary data.

Mr. KOCH. He is a recognized expert in the field.

General HUMPHREYS. Of neurophysiology, yes.

Mr. KOCH. Would you place great reliance on a statement he makes?

General HUMPHREYS. Providing I can see the data.

Mr. KOCH. In this particular area, would you say he has a greater expertise in his particular field than you yourself?

General HUMPHREYS. Without question, sir.

Mr. KOCH. Couldn't we agree with respect to this particular finding, if it is in his field, that you would have to give great credence to it?

General HUMPHREYS. In the field of neurophysiology. Which finding are we talking about?

Mr. KOCH. Is it his field when he says, "I think the level of incapacitation will be substantial in the ability to withstand changes in reentry and immediately thereafter"? That is not his field?

Dr. BERRY. No, sir.

Mr. KOCH. "This is one area where I would feel considerable concern. I would also be much concerned about the sleeping cycles." Is that his field?

General HUMPHREYS. Yes, sir.

Dr. BERRY. You could say it is, EEG, sleep, yes.

Mr. KOCH. And the ability of the man to perform well in consequence? Is that his field?

Dr. BERRY. You could say that.

Mr. KOCH. General, is that his field?

General HUMPHREYS. Yes, sir.

Mr. KOCH. If that is his field, since I gather it is not your field, or to the same extent, is that a fair statement?

General HUMPHREYS. Yes; that is correct.

Mr. KOCH. You would give great credence to what he said?

General HUMPHREYS. I will listen to it and evaluate it.

Mr. KOCH. You are talking about the future tense, you will listen to what he said. Wouldn't it make sense, before you came to a final conclusion and recommended to us we approve and authorize and condone a large expenditure of money, that you talk to him and then come back and tell us whether or not your position has changed before you tell us to do something?

General HUMPHREYS. I don't believe I have told you to do anything. I said, in my opinion, we should not stop our progress.

Mr. KOCH. This hearing is held because we are laymen, at least I am, and we rely on your advice. It isn't simply a question of putting in down in a transcript. When we walk out of here, we are going to say the general told us to do something and we have great confidence in his judgment. No one ever testifies lightly when they come before a committee of this kind, because we are relying on you; and if we are relying on you, isn't it incumbent that you have all the facts before you advise us?

General HUMPHREYS. I think that is true for all of us concerned, all the facts available at the time.

Mr. KOCH. At this time, don't you have all the facts?

General HUMPHREYS. I have what has been made available.

Mr. KOCH. When you said made available, that is at the press conference and briefing of 3 hours, isn't that a fact?

General HUMPHREYS. Plus the charts.

Mr. KOCH. Is there any question in your mind that a little chat with Dr. Adey might be helpful to you?

General HUMPHREYS. As I said, I had a little chat with he and Dr. Meehan both.

Mr. KOCH. At the press conference?

General HUMPHREYS. After the briefing, standing talking about the flight.

Mr. KOCH. How long did that last?

General HUMPHREYS. Maybe 15 minutes.

Mr. KOCH. I am not intending to do anything other than to find out what is the standard of a professional technique in this area. I know that in other areas, when one is engaged in this kind of procedure involving billions of dollars, the lives of men—and I put the lives of men before the expenditures of billions—you don't dispose of it over a 10 or 15 minute chat.

General HUMPHREYS. I haven't disposed of it.

Mr. KOCH. Don't you think we ought to have you back here after you have talked with Dr. Adey to ascertain if you are in accord with him having posted warnings to us?

General HUMPHREYS. I would be delighted to come back when I have seen the data.

Mr. KARTH. Would the gentleman yield?

Mr. KOCH. Yes.

Mr. KARTH. Have you asked for that particular data that you have not seen?

General HUMPHREYS. It is my particular understanding the data belongs to the investigators until they have resolved it and in January is the time they agreed they will have enough to put out the report and so forth.

Mr. KARTH. Have you asked Dr. Adey what particular data he has at this time for your own purusal? Have you asked him?

General HUMPHREYS. Specifically, Dr. Adey, no. I have asked, and received, from Dr. Reynolds' office, what was available. That is where this came from.

Mr. KARTH. The gentleman from New York was exploring fields of competence, and in particular as it related to Dr. Adey, I believe.

Dr. Adey says that the monkey, in his professional judgment, died because of the prolonged weightlessness. How do you judge his competence in that field?

General HUMPHREYS. Well, I think that is Dr. Adey's opinion, sir.

Mr. KARTH. How do you judge his competence in that field to make that judgment?

General HUMPHREYS. I judge Dr. Adey to be a very competent man indeed.

Mr. KARTH. In that particular field, would you judge his professional competence to be equal to yours, less than yours, or greater than yours?

General HUMPHREYS. It is a difficult question. There are a great many fields we are talking about. I think that is rather putting us in a difficult spot for me to say I am better than Ross Adey, and I won't do it, sir, and I don't really think I can answer that question with truthfulness.

Mr. KARTH. But he came to this conclusion, and you do have great respect for his medical competence in some of these fields, all of which have an effect on his final conclusions?

General HUMPHREYS. Yes.

Mr. KARTH. Yet you have already concluded this information is not vital. You think it might be useful, but it is not vital.

General HUMPHREYS. That is correct.

Mr. KARTH. To further prolonged manned space flight under weightless conditions?

General HUMPHREYS. Yes, sir; that is, information we have from this one flight is not vital unless I see more than I have seen now. I will have to put it that way.

Mr. KARTH. You haven't seen much. You are going to see a lot more, I am sure, because you have hardly scratched the surface.

General HUMPHREYS. That is right. I will see more, but I have seen everything that has been presented.

Mr. KARTH. Would you care to withhold judgment on the vitality of this judgment?

General HUMPHREYS. I made a judgment based on the data we have that it is not vital.

Mr. KARTH. I think we have explored this sufficiently well to understand what your judgment is to the question.

Mr. FULTON. Mr. Chairman.

Mr. KARTH. Mr. Fulton. Glad to see you.

Mr. FULTON. The reason for the existence of experts instead of one expert is they are sure to disagree on the conclusions on the facts, as well as the facts themselves. As we build up facts, these are the cornerstones of future judgments; so the question is at some point, when there is disagreement or there are enough facts given to each side in a disagreement, to make a sound conclusion and a recommendation for action. Isn't that the case?

General HUMPHREYS. Yes, sir.

Mr. FULTON. So, at this particular time, it is good that there is a disagreement which makes the various people involved with their experiences and their judgments reexamine these judgments. But that is no reason to stop the program, isn't that right?

General HUMPHREYS. That, I feel, is the point exactly, sir.

Mr. FULTON. The purpose of the research and development program is to change people's minds and take them away from surmises, suppositions, and probabilities into reliable facts so that if research and development is to proceed, of course, various levels of inquiry make certain facts not suitable so they are then not relevant, is that not the case?

General HUMPHREYS. That is true, sir.

Mr. FULTON. So what you are going through in the agency is determining the course of research and development which, of course, leads from a set of facts to further facts, further information. You are not shutting your mind on this, and you are keeping open judg-

ments and open conclusions as you go on as to man's qualifications for space flight as well as the correlation between the monkey experiments with man; is that not correct?

General HUMPHREYS. Yes, sir; that is correct.

Mr. FULTON. I am afraid you are being subjected to cross examination and examination from the other side and this side by two lawyers.

My point is, Mr. Chairman, maybe we are running up the wrong space tree. Maybe we are making experiments on the wrong examples: man and monkeys.

As a matter of fact, in my mind, maybe both men and monkeys are really not efficient for long space flight or it might be impossible and maybe women are the ones. [Laughter.]

Mr. KARTH. Would you buy women or instruments, Jim? [Laughter.]

Mr. FULTON. Instruments of what, Mr. Chairman? I have to know before I commit myself as a bachelor.

Mr. KARTH. Hardware instruments.

Mr. FULTON. I think they are perfectly able to handle many instruments, including men.

Mr. KARTH. You are software, Jim.

Mr. FULTON. Women's metabolism is better. They live longer and last longer. Secondly, women are smaller. They take less oxygen and, of course, consume less calories. They are better equipped for changes of temperature. The are better psychologically and physiologically attuned than men.

Likewise, they are more composed than men. In addition to that, they are better equipped for exposure and their voluntary exposure on earth proves that. They wear a few ounces of clothes, while men wear many pounds to bundle up; and they have no ill effects.

Mr. KARTH. I would like the record to show some of these statements may not be entirely supported by facts. [Laughter.]

Mr. FULTON. May it also show, for the record, it is only hearsay of the chairman, not his own personal investigations.

Mr. KARTH. And the gentleman from Pennsylvania has been known to change his mind in the past, and it may well be both the general and the gentleman from Pennsylvania might want to change their minds.

Mr. FULTON. Never on women in space. [Laughter.]

I am the first proponent, the second, and the only proponent that women should be given their proper place in space, because actually they are the major property owners in this country and they are the major taxpayers, and why do men keep them out? I see the stenographer nodding her head.

Mr. KARTH. I think the gentleman hits a very important point and it is in line with the inquiries being made by this subcommittee. It is the very thing we are doing. We are inquiring as to what experiments have been done, what research has been done, what fundamental knowledge do we have that may well answer the gentleman from Pennsylvania's question. Maybe it is that we should fly women. I don't know how many experiments we have done in this regard. I don't know how much money we spent on it. Maybe it should be primates; maybe it should be men. This is really the purpose of this hearing.

Mr. FULTON. As I recall, both the Russians and the Americans, when they first started putting animals in space, put female animals, both dogs and monkeys. Now we are changing, so we put a boy monkey up

the last time, and maybe he wasn't the right one because the female monkeys all did all right, but nobody ever brought that question up.

I will ask the Doctor, why did the female monkeys do all right, and the male monkey die in a situation with no particular pressures and not much temperature change?

General HUMPHREYS. Sir, maybe he died of shame because his name was Bonnie. [Laughter.]

Mr. FULTON. Maybe he wasn't the right kind of a monkey. [Laughter.]

Mr. FULTON (continuing). He wasn't psychologically adjusted.

Going back to this other, I do have a point, possibly an extrapolation that we should look into the various aspects of how you extrapolate from the previous monkey flights, dog flights, and see whether there isn't some kind of a difference so that it isn't just looking at this one monkey boy and calling him every monkey, so that when you have man, maybe we don't have the right example, and I am very serious about it, because you may have to try some women and see how it affects them. I certainly recommend it.

I don't see why NASA does not, on Apollo XIV, start in with a woman scientist in space. It is like one of the scientists who came up, Dr. Dryden, before our committee once, and said to me, that is just like putting a women in a cannon and shooting her out of the cannon when I asked him about an experiment.

My comment was, well, let's put one in and see what happens. But, you see the idea of looking at this in a serious vein on these angles, people would rather take it as a joke, and I am very serious about it, that I would like a correlation between the monkeys on the various sexes and see what happens. Maybe we are up the wrong tree.

That is all, Doctor.

Thank you, Mr. Chairman.

Mr. KARTH. Thank you, Mr. Fulton.

Incidentally, this last Apollo launch just the other day, have we determined for sure whether or not lightning struck the vehicle on takeoff?

Dr. BERRY. We have not yet.

Mr. KARTH. We have not yet made that firm decision?

Dr. BERRY. No, sir.

Mr. KARTH. We have decided, however, to never launch again in a rainstorm?

Dr BERRY. There is a great deal going on in that area, looking at what actually happened and exactly what they ought to do.

Mr. KARTH. Haven't they made that decision?

Dr. BERRY. I can't answer that, because that is not really my decision to make.

Mr. KARTH. I read it in the newspapers. I wondered if it was a valid quote.

Dr. BERRY. I think Mr. Paine has a group of people looking very carefully at the whole launch situation right now to determine what we think really did happen from all the data that is available and to try and decide do we need to make any changes in mission rules.

Mr. KARTH. I think it is very sensible to make an indepth study of what happened, because the safety of the astronauts is at stake, and until such time as the study reveals the answer, so far as I understand,

there will be no more launches during rainstorms. I think that is the right decision. We are just kind of wondering why this same kind of a decision might not also be required with respect to bioscience—that we have some more indepth investigations and some more indepth experiments to make sure that what we don't know is jeopardizing the well-being of the astronauts. I think we all agree with that.

Dr. BERRY. Absolutely.

Mr. KARTH. You have heard of the White House Science Panel's report? The PSAC report?

Dr. BERRY. Yes.

Mr. KARTH. Let me just quote from this article:

> A White House Science Panel said yesterday—that was on the thirteenth—that NASA has failed to do enough biomedical research to justify the use of man rather than remotely controlled machines on future space missions, and recommended that the agency postpone work on major new manned space systems until the mid '70's when this research can return results.

Do you agree or disagree with the White House Science Panel?

General HUMPHREYS. Sir, that is a quote in the press. I would like to read it. I have not read it. I just received it.

Mr. KARTH. If that is the conclusion they did come to, would you agree or disagree with them?

General HUMPHREYS. I guess I have already gone on record, sir, as saying I don't think we should postpone going forward with planning future missions. So I would be reversing my stand if I said I thought we should stop everything until we do.

Mr. KARTH. You disagree with their conclusion if that, in fact, is their conclusion?

General HUMPHREYS. If that, in fact, is their conclusion.

Mr. KARTH. Again, the working group found that while NASA has successfully developed a capability for manned space flight—here is a direct quote:

> Possibilities for maximizing man's contribution to the total system reliability and performance have not been determined, nor have alternative strategies been properly explored, such as substitution of man's sensory and manipulative capabilities with automated subsystems.

The report says that the possibility of maximizing man's contribution to total system reliability and performance have not been determined, nor have alternative strategies been properly explored.

You agree with that or disagree?

General HUMPHREYS. I don't think they have been fully explored.

Mr. FULTON. Mr. Chairman, may I comment on that?

Mr. KARTH. Jim, it is late, and I would like to get the opinion of the witness.

Mr. FULTON. Very short comment.

Mr. KARTH. All right.

Mr. FULTON. On the Apollo XI flight, if man had not been present, it would have been a disastrous, ghastly failure; so that comes a balancing point where you do need the men with their minds and their judgment and their prehensile, tactical abilities which will make greater successes and lower costs in the long run.

Mr. KARTH. Let the record show that the gentleman from Pennsylvania's opinion is not necessarily supported by irrefutable facts. Let the record also show that the first soft landing on the moon, the first

time it was attempted, was done without man. I choose not to get into the argument about man's ability versus automated spacecraft; but if we want to put something in the record, let us also put into the record that the Surveyor flight and soft landing was one of the most, if not the most sophisticated, difficult project undertaken by the space agency, and that it was, in fact, completed successfully the first time it was ever attempted—back in April 1967.

General, the PSAC group conceded that man would probably be necessary for exploration of the planets, but said that manned planetary flights are so "remote that the question of man's tolerance for 700-day missions seems less important than the question of man's utility in post-Apollo lunar exploration and in providing engineering assistance to possible complex space systems in earth orbit for scientific purposes. For this reason, we feel the posture of efforts in manned space flight should be shifted from tolerance for flights of longer durations to modes and levels of effectiveness of man assisted systems on the moon and in earth orbit."

You agree or disagree?

General HUMPHREYS. I agree that in the near term we should be spending our time as they have recommended, but keeping in mind the future of planetary exploration.

Mr. KARTH. The report criticized NASA for igoring the question of NASA's effectiveness in space, and said the Nation is not now prepared to conduct research in the space biomedical field.

You agree or disagree with that?

General HUMPHREYS. I think there is a great deal lacking in the Nation in the way of multidisciplinary teams and interfaces between the biological scientists and the physical scientists and engineers that are needed in institutions to carry out what would really be an ideal and best form of biomedical research.

I do agree that the capability within the Nation as a whole is short and is lacking.

Mr. KARTH. Another quote, General:

> We are convinced that the necessary biomedical foundation for the design of optimum flight programs to explore questions of man's effectiveness in space do not yet exist either in NASA or in the scientific community at large. NASA, without recognition of the importance of these foundations and without the major modification in its approach to space biomedicine, would only be able to conceive empirically designed manned programs which promise slow and very expensive progress toward the understanding of man's optimum role and intrinsic capabilities in space.

You agree or disagree with that?

General HUMPHREYS. In its total context, I think I agree.

Mr. KARTH. One of their recommendations, General, was that:

> A sustained effort be exerted by NASA to develop close communications with the biomedical community in general, including a broader use of biomedical scientists in space program planning.

You agree with that?

General HUMPHREYS. Naturally I would agree with that. Biomedical scientists are short and would like a much wider say in almost everything.

Mr. KARTH (reading):

> That NASA establish a program to enlist the services of biologically and medically trained astronauts.

Do you agree with that?

General HUMPHREYS. Yes, sir; and we have some.

Mr. KARTH (reading):

That NASA consider new organizational forms suitable for an expanded and upgraded biological-biomedical effort with biological and medical operations unified within the agency.

You agree with that?

General HUMPHREYS. Totally; no, sir. In the idea of unification and increasing the scope of the work; yes, sir. I think biology is a continuum from cell to man, and I don't think you can separate it.

Mr. KARTH. General, on page 5, you and Dr. Berry say, and I will quote the sentence; it is in the middle of the page: "As you know, we had planned a limited number of inflight medical experiments for Apollo, but the operational constraints prevented us from implementing them except as detailed preflight and postflight," and so forth. Would you, for the record, provide the committee with the list of those constraints?

General HUMPHREYS. Yes, sir.

Mr. HAMMILL. Mr. Chairman.

Mr. KARTH. Counsel.

Mr. HAMMILL. Would it be possible also to furnish the committee with a statement as to specifically what medical measurements you had intended to carry out, but were not permitted to carry out?

General HUMPHREYS. Yes, sir.

(Information requested is as follows:)

Changes associated with the Apollo 204 accident, resulted in problems of continued weight growth in the command and service module and the necessity for retraining of flight crews. To minimize mission complexity and thus better assure a successful lunar mission buildup, it was decided to delete almost all experiments which required inflight performance. Those experiments which could not be accommodated in Apollo were planned for assignment to the Apollo Applications Program.

As a result of this action, the following inflight medical experiments were deleted from Apollo:

M-003	In-Flight Exerciser	M-012	Exercise Ergometer
M-004	In-Flight Phonocardiogram	M-017	Thoracic Blood Flow
M-005	Bioassays Body Fluids	M-018	Vectorcardiogram
M-007	Calcium Balance Study	M-019	Metabolic Rate Measurement
M-009	Human Otolith Study	M-020	Pulmonary Function

With the deletion of the above experiments four medical objectives remained which are considered necessary for the successful completion of the Apollo Program. In order of their precedence, these objectives are:

1. To insure crew safety from a medical standpoint.
2. To improve the probability of mission success by providing medical information necessary for mission management.
3. To prevent back-contamination from the lunar surface.
4. To continue to further the understanding of the biomedical changes incident to space flight.

The achievement of these medical objectives in the Apollo Program is accomplished by the collection and analysis of selected quantitative data telemetered from the spacecraft together with inflight crew status reports and a carefully conducted pre- and post-flight medical evaluation consisting of an integrated package of tests.

Inflight telemetry data includes selected electrocardiographic data during various crew activities and continuous information concerning performance of bioenvironmental systems.

Crew status reports are furnished via air to ground communications and a system of inflight logging. Crew status reports provide a method of acquiring data on food and water consumption, certain radiation dose readings, sleep and

exercise information. In the event of inflight illness, symptoms and treatment are transmitted over this air to ground communication link between the crew and physician.

Pre- and post-flight evaluation in support of the Apollo medical objectives include specific tests which have been carefully and critically selected to provide the maximum amount of useful data. These clinical laboratory tests include a physical examination, microbiology test, immunology test, hematology test, biochemical test, cardiopulmonary assessment and for some of the earlier missions, a bone densitometry evaluation.

The physical examination aids in assessing the general health of the astronaut and to detect any problems which might require remedial or preventive action to assure optimum performance during the mission. It is also used to document the crew members physical condition for post-flight comparison.

The remaining tests are used as an aid in assessing the physiological state of the crew and to detect any changes which might occur due to space flight. The immunology test is used to determine the time course, extent and etiology of any changes in he humoral and/or cellular immune status of the crew members. It is also used to assess man's ability to combat infection and repair traumatized tissues after exposure to weightlessness, sublethal ionizing radiation and the immunologic stimulation of the closed environment.

The hematological tests are performed to study the time course, extent and etiology of alterations in circulating red cell mass and leukocyte kinetics. Determinations are also made of any changes in the clotting mechanism and the effect of inflight radiation on white blood cell chromosomes (Cytogenetic Blood Test).

Biochemical tests are conducted to determine the extent and time course of alterations in fluid and electrolyte balance and musculoskeletal metabolism as reflected in selected biochemical constituents in blood, urine and feces.

Microbiological tests are used to determine the effects of space flight on the microbial flora of crew members and the spacecraft in order to detect any species changes which occur and can be recognized and differentiated from potential extraterrestrial contamination.

Cardiopulmonary assessment is made to document and evaluate the extent, time course and etiology of decreases in the effectiveness of cardiovascular adjustments to gravity following space flight as reflected in Lower Body Negative Pressure and Exercise Capacity Tests.

The Bone Densitometry Test was used to assess the skeletal status of each astronaut prior to and following flight in order to determine the extent to which skeletal integrity has been maintained or degraded during flight.

During lunar surface extravehicular activities, selected telemetry measurements and the astronauts voice record are used by the physician to determine the rate of energy expenditure of crewman. This determination is made indirectly using a metabolic computation program based on three separate measurements. Heat production is calculated from oxygen usage and the amount of heat taken up by the liquid cooled garment as determined from telemetered measurements of the Liquid Cooled Garment water temperature inlet and outlet temperature differences.

Mr. KARTH. Is there any evidence, to your knowledge, General, that the Soviet Union has decided to hold in abeyance for 5 years a long-duration in-earth-orbit manned space station?

General HUMPHREYS. There certainly has been talk in the press, hearsay evidence, I do not know. I talked to some of the Soviet biomedical people at the last opportunity I had, which was in the spring. However, Dr. Berry has recently been to Russia and spent some time with them, and I think he can probably answer this with more authority than I can.

Mr. KARTH. Dr. Berry.

Dr. BERRY. I had an opportunity to spend 10 days with some of our medical counterparts in the Soviet Union at their invitation in the latter part of September, and I saw no evidence that they are slowing their program at all.

As a matter of fact, from the medical point of view, I think they have somewhat changed some of their initial ideas about the pace from a medical point of view, and I think they were tending to hold it up medically earlier in the game.

They are aware of the same kinds of findings that we have had. They are fully aware of our data. We discussed at great length the laboratory they have set up to investigate the weightless changes, and they are looking at exactly the same things we are looking at.

They are looking at the cardiovascular deconditioning. They are looking at the calcium loss, at exercise capacity, the same things we are. Their view, at the present time, is very similar to what we have expressed here this morning in that they feel that the extension of man's time for long-duration space flight is something that we certainly should do and that it needs to be investigated in the in-flight situation, and we need to get data from prolonged exposure. I think they are going to do that with a space station of some sort, and that is the general impression from all the discussions I had at some length with these people.

Mr. KARTH. Was there any implication that this decision to delay for 5 years might be medical or biological?

Dr. BERRY. No, I don't think so, Mr. Karth, at all. I did not have that feeling. I never had it expressed there was a delay for 5 years, because all the talk that I had with the medical people, or the people in the Academy of Science or the Committee on Exploration of Space, never said that. I know that has been expressed in the press since my return, but it was never said there.

Mr. KARTH. It was recently published.

Dr. BERRY. Professor Keldish stated it here.

Mr. FULTON. May I be heard on that point?

Mr. KARTH. Yes, sir.

Mr. FULTON. Being on the Foreign Affairs Committee, there has been testimony that because of the technological lag that is now becoming more apparent between the United States, Western Europe, and the U.S.S.R., there is a change of general U.S.S.R. policy which favors, of course, the arms limitation and the SALT, Strategic Arms Limitation Talks; so that may be an overall policy that is causing the change of policy of the U.S.S.R., rather than anything scientific.

Could that be a possibility?

Dr. BERRY. It is possible.

Mr. KARTH. I really don't know. I would say to the gentleman from Pennsylvania that I was merely trying to explore with the witnesses whether or not, in their association with the biological scientists in the Soviet Union, that might have been given as a reason.

Mr. FULTON. My final point on the Apollo XI, there is no doubt that in order to reach the moon and reach there first in time, which was a world first and certainly put our technology first in the world's opinion, there had to be a sacrifice of time on the moon, as well as experiments to increase the margin of safety of astronauts, is that not correct?

Dr. BERRY. That is correct.

Mr. FULTON. I must quote Admiral Rickover as an old Navy fellow. He said, "If I were able to put a nuclear submarine in space and then orbit the moon with it, someone would be sure to say it

went the wrong way around, and, second, the wrong fellow did it."

So we got to the moon first, and we ought to be very pleased and proud of NASA.

Thank you, Mr. Chairman.

Mr. KARTH. I doubt seriously that there is anyone here or anywhere else that is not proud.

Mr. FULTON. There should have been more experiments that would have caused a greater delay, rather than simply sending the men to the moon.

Mr. KARTH. If you had been here during the entire course of these hearings, you would have understood the purpose of these hearings is to make decisions, hopefully on the basis of evidence and facts, with respect to future prolonged manned space flight as related to the bioscience field.

Mr. FULTON. As the chairman well knows, with all good humor, he and I have disagreed with the emphasis between manned space flight and unmanned. I want a balanced program of both, and I think the gentleman has certainly emphasized unmanned space flight.

Mr. KARTH. The gentleman stated my position. I want a balanced program between the two.

Mr. FULTON. Which makes a difference in opinion.

Mr. KARTH. And if the gentleman from Pennsylvania also wants a balanced program, then the record ought to show there is no difference of opinion.

Mr. FULTON. There is a difference on the seesaw in the amount of weight.

Mr. KARTH. One last question, Dr. Berry or General Humphreys.

Have the Russians flown more bioscience experiments on their manned space flights than we have?

Dr. BERRY. You mean animals on their manned flights?

Mr. KARTH. No.

Dr. BERRY. You mean did they get more data?

Mr. KARTH. Yes, have they accumulated more scientific data on manned flights than we have?

Dr. BERRY. As far as the number of types of sensors and things of that sort, yes, they have accumulated more in types of data that were obtained. Their conclusions from that data do not differ from ours and, as a matter of fact, in discussion with the Russians, they are willing to admit, at this point in time, they did some things early in their program they would not do again in that they flew some instrumentation which was instrumentation without good ground-based data. They were flying very early instrumentation. They didn't have good ground-based analogs for it, and thus it confused some of their findings from the flights because they could not interpret exactly what that data meant, and I think that is a very important point. If you are going to use some instrumentation in flight, you have to be sure what data you are going to get from it so you can interpret correctly what you are seeing, and they are willing to admit that was the case.

Mr. KARTH. I think their ground-based instrumentation probably is not nearly so good as this Nation's. At least there is every evidence, to my knowledge, that they hardly compare.

Dr. BERRY. I would agree with that.

Mr. KARTH. Are there further questions?

Thank you very much for appearing before the committee, General Humphreys and Dr. Berry. We appreciate greatly your being here, and I think you have assisted this committee toward formulating a final judgment as to what we might recommend.

At any rate, we do know you are very busy people. We know you are very dedicated people. We know you have the very best aims and objectives at heart, whether there are disagreements within the professional community as to how to best reach those goals and objectives. Of course, those are differences of opinion that this committee has a responsibility to evaluate and render a judgment on.

So, we are indeed grateful you could come and take time out of your very busy schedules to assist us in that regard.

Mr. KOCH. Not a question, but I think I might pose a request.

That is, General, after seeing Dr. Adey, if you come to a different conclusion, would you advise us?

General HUMPHREYS. I will do that, sir, with a great deal of pleasure.

Mr. KARTH. Thank you very much for being with us.

Dr. Warren, I suppose most everybody would like to go grab a bite to eat, and I wonder if it is possible for you to come back at 2 o'clock.

Dr. WARREN. I will be glad to.

Mr. KARTH. I am very sorry you have been delayed in giving your testimony.

Dr. WARREN. I have a 4:40 plane to Columbus.

Mr. KARTH. If we could reconvene at 2 o'clock, and if counsel would notify the committee members, we would appreciate it greatly, Doctor, and we will try to get you out of here in time to catch your plane.

Thank you very much.

(Whereupon, at 1 p.m., the subcommittee recessed, to reconvene at 2 p.m., room 2325.)

AFTERNOON SESSION

Mr. KARTH. The committee will resume its sitting.

We are privileged to have as our witness this afternoon Dr. James Warren, who is chairman of the department of medicine, Ohio State University, at Columbus, Ohio.

Dr. Warren, we apologize, again, for not getting to you this morning, but we were very pleased that you would stay with us. Please proceed and give whatever testimony you feel will benefit most the committee and the determinations the committee must make.

STATEMENT OF DR. JAMES V. WARREN, PROFESSOR AND CHAIRMAN, DEPARTMENT OF MEDICINE, OHIO STATE UNIVERSITY, COLUMBUS, OHIO

Dr. WARREN. I am pleased to be here, Mr. Karth.

I have been away for several days from Columbus. I am not too happy about my prepared statement; it was done on the run.

I think—could I summarize it, but there are certain sections that are dealing so much with the discussion this morning that I might leave out part of it.

If I could go through it with some omissions, I would like to do that. I am delighted to have the opportunity to appear before you today as a civilian witness on matters concerned with bioscience and the space program. Although I have not been a direct participant in the space efforts, I have served for a number of years as a consultant to various components of the National Aeronautics and Space Administration related to biomedical programs. As a member of the Space Medicine Advisory Group of the Office of Manned Space Flight, I participated in a projection of a long-range program of biomedical exploration. More recently, and from a different vantage point, I served as a member of the Space Science and Technology Panel of the President's Scientific Advisory Committee. As you know, our report on biomedicine in the space agency was released last week. Today I come as an individual interested in biomedical research and education and as one who carries a considerable degree of interest in these affairs day to day.

I would first like to comment on the role of medicine and biology in the space program. Why is it there at all? It strikes me that there are two main purposes, interrelated, but which should be recognized for their different, but related goals. The first purpose is operational. With the participation of man in space flight, his capacity to function properly over a period of space flight has been studied and observed in a way that is essentially no different from that in which the space agency studies the ability of a tape recorder or any other piece of hardware to function in space. The second purpose is to conduct biomedical research utilizing the unique circumstances of space. This research should contribute to the former purpose. It is in the second purpose that I feel that new emphasis should be placed. We know now that the basic job can be done, and our preoccupation with immediate flight problems may be lessened.

Despite many dire predictions in the early days of the space program, man's performance has been remarkably good. There are, however, indexes which indicate that the body is affected by this new environment although the deviations from normal are not substantial enough to alter his ability to perform in the space flights to date. They constitute signals that space flight is not totally without effect on man. The observations of man's performance and the measure of his reactions are the role that the Air Force ascribes to its flight surgeons. This activity is clearly an important aspect of man's space flight. It is perfectly obvious that man can well tolerate missions of current length but the major question before the house is can man tolerate missions of the length required to venture to the planets, such as Mars. We don't really know yet whether we want man to go to Mars but the best medical opinion would be that, if we are able to contemplate this, even as a possibility, a long-term preliminary program of study will be required. In other words, the leadtime required to give an answer to whether man is able to go to Mars is lengthy. It would appear to me that if we even consider it only a possibility that man might want to go to Mars, we should start now in establishing this medical baseline. This calls on a coordinated program of biomedical research. If we wait until a decision is made that we do want man to go to Mars, then the implementation of the decision would have to wait for a number of years for the basic biomedical research to be carried out.

Furthermore, the basic biomedical research would appear to be valuable in its own right.

We are all aware that the space program has had many rewards. If we grant, for the moment, that the United States is going to continue to have a space program, it would appear most unfortunate not to reap the rewards for biomedical research. Space offers a unique new dimension for studies in biomedicine. I don't know that the totality of the space program could be defended on this basis and this basis alone. There are many problems for study. These range from the growth of wheat seedlings to complex problems involving the heart and circulation in man. Purely on the basis of science and our image in the world, I would think that we should pick up this opportunity. The biostatellite program was an attempt to do this. Unfortunately, the division of NASA into three large units has made it appear that such a program is indeed competitive with man's space flights. To me, the most important point to make is that biology is a continuum. Research on seedlings or bacteria may yield results that have a direct applicability in man. Medical advances such as the famous "blue baby operation" have taken place because they represented an appropriate cooperation between animal studies and experience on man.

This does not mean that one must do everything in the experimental laboratory first and only after the conclusion of this turn to man. Let me give another example. Transplantation of the human kidney is an increasingly successful and useful clinical procedure. Certain fundamental early studies were done on animals. If we had continued to work with animals and animals alone, we might well have been discouraged because the results were not too good. Early studies on man were more rewarding. Now animal and human studies continue to be done to investigate means of making the procedure even better. An appropriate mix of laboratory and clinical investigations would appear to be the best way to increase the efficiency of this type of medical treatment. Although we have not proceeded as far, I believe that the same can be said in the field of heart transplantation.

May I interject here that if the first heart transplant had been a total failure—this is now viewed in the light of experience with Bonny—why we wouldn't have said we never could do this. And I think the failure of Bonny to survive shouldn't turn us against further research on primates.

I therefore believe that it is most unfortunate that the space agency's organization has brought about a division that appears to pit the forces of laboratory investigation against those who operate man's space flight program.

The recent biomedical report of the space science and technology panel of the President's Scientific Advisory Committee indicates dissatisfaction with the organizational ability of NASA to mount a broad program in biomedical research. This is not a criticism of the individuals involved but indicates more a question of the agency's organizational desire to move forward with problems in biology and medicine. The role of the flight surgeon, although complementary and, in many ways, interrelated, is not the same as that of the biomedical research worker. In the large Manned Space Craft Center in Houston it is striking how few members of that facility come each day with the primary objective of working in the laboratory on fundamental

biomedical problems. The communications between the scientists at Houston and those in other NASA facilities, such as the biomedical group at Ames, are remarkably meagre. It would seem to me that the time is overripe for a coordinated internal program in the agency to push forward a vigorous broad program of biomedical research. There are many fine people in various aspects of the space agency who desire to do this but the total coordinated effort has not been mobilized. This is not a new view because, as you note in the President's Scientific Advisory Committee's biomedical report, advisory groups have stated this on several occasions during the last decade.

To be sure, the space program has been a triumph of engineering capability. Its early and basic management has appropriately been in the hands of the engineers. Biomedical experiments have been flown on a contingency basis. I believe, also, that the budgetary presentation have also reflected this relative priority. Perhaps there may be lack of understanding. We read, for example, in the newspaper that a Saturn V rocket has been qualified for flight after one major flight. I recognize that many preliminary operations went into this conclusion. On the other hand, in biology, the success of a kidney or heart transplant program would not be established by one success. The demonstration that vaccination against poliomyelitis was effective required many thousands of individuals. Man is a complex machine and, unlike a rocket, we don't have the blueprints of his construction in our hands.

I would strongly support the recommendations of the biomedical report of the President's Scientific Advisery Committee panel that a strong program of biomedical research integrating both animal and human studies would net the greatest reward for this country and mankind from the unusual opportunities presented in our space program. Compared with other features of the space program, such an effort in itself would not be terribly expensive. It would keep our options open for the possible participation of man in longer duration space missions to the planets in the days to come.

My points before this committee are therefore simple and I have tried to state them briefly. They may become confusing in that they intertwine the development of a good scientific program in biology and medicine with the maintenance of a first-class medical care program for the astronauts, but they are not the same. I believe strongly that a well organized program of capability in biomedical research, cutting across all of the divisions of NASA, would be most rewarding. It would remove some of the apparent conflict between biosatellite programs and the programs of manned space flights. It would place biomedical research on animals as an important component in the NASA program, being reflected in overall planning and operation of the mission. Animals and man might fly in the same vehicle, and a more effective program result. A biomedical program would bring, I believe, a greater degree of participation of the academic community in the scientific activities of the space agency, a point that has been commented on recently in various other scientific disciplines. I recognize deeply the competition for dollars and the broad problems of supporting biomedical education and research in the United States. A program of the type discussed here would, I believe, fit into and help support our national biomedical efforts in a beneficial way. It

could be utilized by our universities in biomedical training and research.

Biomedical research in space is difficult, but it seems to me most disappointing that this unique opportunity cannot be captured by our country and interwoven with the fabric of our whole biomedical activities in educational institutions and medical centers across the country. Its cost would not be great and the establishment of a first-class program with a coordinated effort might save millions of dollars in unfortunate or poorly planned space flights in the future. It is a type of insurance that I suggest so that we will obtain the greatest reward from our space efforts.

That is all, Mr. Karth. I will be happy to answer any questions.

Mr. KARTH. Thank you very much, Dr. Warren.

It is a very concise statement. We appreciate greatly your benefiting the committee with it.

Mr. Pettis?

Mr. PETTIS. No questions, Mr. Chairman.

Mr. KARTH. Mr. Symington?

Mr. SYMINGTON. Thank you, Mr. Chairman.

Dr. Warren, you were here this morning, I believe?

Dr. WARREN. Yes.

Mr. SYMINGTON. I would think you might have gathered some concern that was expressed from this side of the table about a sense of a lack of high regard for the biosatellite program, of its importance to the manned space effort. I take it that you have a high regard for the biosatellite program and the contribution that it can make to the manned space effort. It is clear from your testimony.

Dr. WARREN. Yes; I would say that I think the goal is highly desirable. I think that in some ways—and I am not sure I am technically competent to say this—that the way it has been operated, with its own hardware and so forth, may have, in a sense, forced it to operate with one hand tied behind its back. But, yes, I definitely feel that is commendable and desirable.

Mr. SYMINGTON. We had testimony last week from Dr. Adey. Certain questions, including one important one that I wish we had recalled this morning, was when the chairman, Mr. Karth, asked Dr. Adey if he thought we had learned more from the Russian biosatellite, that is, from the Russian manned space effort concerning the effects of space flight on man than we had learned from our own. Dr. Adey, as I recall, answered almost a simple "Yes." There were two other witnesses who felt that the information was of a different character, but very valuable, from the Russians today. We also had testimony that we learned more from our manned space effort than we learned from our biosatellite effort; that is to say, the instrumented monkey gave us less reliable information than we got from whatever we could derive from the manned space flights—the 5,000 hours in the air.

Yet the reason the Russians were able to give us, according to last week's testimony, better evidence, is that some of their astronauts were instrumented to some extent similarly to Bonnie.

Clearly, this morning's witnesses made a commentary on the value of the Russian space effort as well as on the value of our own, which was in direct contrast to what was told us last week.

Now, you are in this field. You have testified of the importance of the biosatellite program. What would your response be, if you consider

you know enough about it, what would your response be in answer to that question? Have we learned more from the Russians than our own program and what parts of our program?

Dr. WARREN. Unfortunately, Mr. Symington, I am not totally conversant with what the Russians have done in their program. I am under the impression that they have had more points of observation per flight than we have, but I am not under the impression that the instrumentation goes anywhere near as far as in the primate. I would think because of the numbers and our closeness, that we probably, in a sense, learned more from our own human experiments than the Russians, but I don't answer that with a great deal of certainty.

Comparing the manned experience with the biosatellite experience seems to me somewhat unfair, that if it were a football game, that we have had a lot more plays on the manned side than we have on the biosatellite side, and to continue the analogy, the biosatellite, the last play was sort of a broken play and didn't really go as well as planned. So that I think, I would say that the weight of flights would say that we have learned a considerable amount from manned experience.

Actually, he has done it, and it is hard to argue with that kind of subject. On the other hand, an elegantly designed and operated biosatellite flight would seem to me could yield a vast amount of information, far more than one flight from a manned space flight participation. And as I said in my testimony, I think perhaps the most rewarding of all would be a combination, where there would literally be an animal caretaker, and some of the questions we have about the primate would not have to be guesses, but if somebody were there to look, I think we could have gained a lot more information.

Mr. SYMINGTON. If I can ask you a broad question, because I am sure with your keen interest in this whole matter, you can pinpoint areas where you would differ with expert testimony. Since you were here this morning, can you tell us whether any particular statements of either witness gave you particular concern, statements with which you would have differed? I say it that way in order to save time, rather than go over each one. I said with confidence that you must have differed with some of them based on your prepared statement.

Dr. WARREN. Yes. I would point out, before I answer, Mr. Symington, that Dr. Orr Reynolds, who is here, is a friend of mine, and General Humphreys and Dr. Berry. I have known them all and respect their ability. I suppose the biggest single thing that worries me is I can't quite put it in the best words, that they each have their own operation to look after, and the lack of working together, which I think, to me is the most worrisome feature about it, and that is why I maybe belabor the point of coordination. I don't think it is a question of animals or man, I don't think it is a question of one or the other first, but I think it is really the matter of interweaving the program in a way to get the best, the most valuable information from the flights. That would be my real point of apprehension.

Mr. SYMINGTON. Well, then, you would certainly have been apprehensive about General Humphrey's statement that the animal flight was not a necessary precursor to the manned flight program.

Dr. WARREN. Historically, we did do animal flights. I think Ham was—wasn't he the primate that flew first, really, in the American program. So the facts are, as I see them, we did precede man's flight

with animal flights and I would think this would be quite appropriate, I will agree with General Humphreys in the sense that we don't need to go down the absolute ultimate experimentation with animals before we could appropriately begin with man, and again the history is we did not do that. We started manned flights after a very small number of primate flights.

Mr. SYMINGTON. I take it, you are giving me your position?

Dr. WARREN. Right.

Mr. SYMINGTON. And you are explaining that we have derived benefit. It appeared to me that the head of space medicine, Dr. Humphreys, really wasn't gratified or much helped by any of the animal flights, or at least, that seemed to be the thrust of his testimony. Laudable experiments, but why laudable unless they had some relevance to man. It was never made clear to us why he thought they had any value as they applied to man. Indeed, he seemed to deny that they did.

Dr. WARREN. My primary interests are in the heart and circulation, and though I think it would be wonderful if we could devise so-called nonevasive techniques for giving more information about the function of the heart and circulation, at the moment we don't have those methods, and therefore it seems to me that a complete exploration of cardiovascular physiology in space flight really can only be done in the experimental animal at this time, and therefore, I would think that this would be highly desirable. I think the other point that I would say is that we have done fairly well, so far, on incremental flights of a few hours to a few days, now up to 14 days, that we are now faced, if we look ahead, to almost a difference of magnitude. You talk about a 2- or 3-year flight. And I am less happy about approaching that by means of a gradual step-up in the time, and I think we are going to need a considerable amount of really basic cardiovascular and other biologic information before we project ahead, and it seems to me at this time while we are thinking about whether we, as a nation, want to try to send a man to Mars, is an opportune time to get some of this basic information.

Therefore, that is why I say I would like to see, personally, some animal flights at this time.

Mr. SYMINGTON. Wasn't Bonny, in fact, the first orbital experiment that we have engaged in of any significance using a primate?

Dr. WARREN. Yes.

Mr. SYMINGTON. Ham——

Dr. WARREN. Ham was suborbital.

Mr. SYMINGTON. Right.

Dr. WARREN. I think that is right.

Mr. SYMINGTON. So this was of a different magnitude?

Dr. WARREN. Yes.

Mr. SYMINGTON. And of a different importance?

Dr. WARREN. Yes.

Mr. SYMINGTON. In General Humphrey's testimony he pointed out that the primate was constrained, that he was instrumented, that he didn't have periodic opportunities to confer with the ground stations and that he was also unclothed, which I thought was perhaps quite normal for a primate. [Laughter.]

Mr. SYMINGTON. But in any event, I was wondering as he placed all these qualifications against the value of the primate's experience, if we could remve all of those constraints, and the clothes, too, and let him fly in a normal environment for a longer period of time, perhaps even in a space station, visited at intervals by humans, wouldn't we be learning something quite valuable about, say, the Mars trip, for example?

(Dr. Warren nods.)

Mr. SYMINGTON. And yet I know of no such plans. And yet that trip is just a decade or so away, according to reports?

Dr. WARREN. Yes. I would agree with you.

Mr. SYMINGTON. Thank you.

Mr. KARTH. Thank you, Mr. Symington.

Mr. Mosher?

Mr. MOSHER. Mr. Chairman, I am sorry, I came late to hear Dr. Warren's testimony, so I guess I better not ask any questions at this point. As a fellow Ohioan, it would be tempting to talk about the far out space of the football world in which Ohioans orbit right now, but I won't go into that.

Dr. WARREN. Mr. Mosher, I used the football analogy a minute ago, and I worried I might be showing my colors that way. [Laughter.]

Mr. KARTH. You are sure you don't want to explore in greater depth?

Mr. MOSHER. No.

Mr. KARTH. The football a bit?

Mr. MOSHER. Not at this point. It speaks for itself. [Laughter.]

Mr. KARTH. Doctor, you said that we could not expect to do any cardiovascular invasions of the astronaut. I don't think there is anyone who would argue with you on that. And therefore it is essential that we do it on the primate. You must conclude by making that statement that whatever the results of that implantation is, that is whatever the results of the experiment is, there must be some potential extrapolation between what you found out from the primate and to the man. Would you care to address yourself to that?

Dr. WARREN. Yes; I think I would agree with what you say, with the emphasis on the word "potential." I think much basic scientific research is done without an obvious and direct relationship to medical practice and medical problems. Just off the top of my head, I can't think of a good example right at the moment, but I think this is fundamental in the concepts of biological research. And just knowing more about the circulation and how it functions, getting a little closer to what the blueprints really are, I think will enable us to be more intelligent in looking at the men's problems or more protection for long-range space flight. I mean by long-range in this context, Mars, et cetra.

Mr. KARTH. And could you only really do that effectively and in a meaningful way by implantation; is that correct?

Dr. WARREN. Yes; really, at this time. I won't—may I make two points?

I wouldn't write off the possibility of, let's say, catheterizing a man in space in an orbiting laboratory. I can say personally, I was catheterized in the very early days of cardiac catheterization and survived this and I can see in an orbiting laboratory, with several biomedically

trained people there the possibility of doing this. On the other hand, it isn't here at the moment. Therefore, I would feel that animals would be the appropriate type of study object in that case.

Mr. SYMINGTON. Dr. Adey feels very strongly that the results of experiments on Bonnie can in fact be extrapolated to manned space flight and long-term weightlessness effects upon man. Dr. Humphreys disagrees. Would you care to address yourself to that dispute?

Dr. WARREN. I talked with Dr. Adey about the——

Mr. SYMINGTON. Whose judgment do you come closest to supporting?

Dr. WARREN. I hate to hedge on the answer to that, but let me try to explain why I would. I really doubt—it may have appeared that Dr. Adey wanted to base the whole new program on this one experiment. I would guess, however, that if Dr. Adey were quizzed about this, he was speaking more about a series of experiments of this type, and I think what General Humphreys was denying was that you could extrapolate very much from one animal experiment in which the animal died and that there were such a multiplicity of factors involved.

I think a cautious biomedical scientist, as I tried to point out in my testimony, had learned the lesson, that the first experiment so often goes the wrong way, so to speak, that one would like to see others done.

I think the point, though, that Dr. Adey, if I can make a guess, was that we should utilize animal experiments to help guide us. And with that I would certainly agree with him.

Mr. SYMINGTON. Well, you do feel that an extrapolation can be made, don't you?

Dr. WARREN. I worry about the definition of the word extrapolation, but, yes, I think the general needs in research can be derived from animals. If we transplant a kidney into an animal and he rejects it, it is a good bet that this is going to happen in a human. As I pointed out, though, the rate of rejection, the percentage that are rejected in animals, to use the kidney, is higher, actually higher, than it is in man. So that it isn't—it is a qualitatively and it may not be a quantative extrapolation. I think most medical people will believe that in the final analysis, medical information of almost any sort to be truly applicable in man has to be tested in man. This is not to belittle in any sense, however, the great need for animal experimentation.

Mr. KARTH. Well, I don't think that Dr. Adey was suggesting or for that matter testified to the thought that we ought not have manned space flight experimentation going hand in hand or in concert with substantial primate or animal experimentation. I think that is really what he was suggesting we do.

(Dr. Warren nods.)

Mr. KARTH. To the contrary, I am not so sure that General Humphreys, for example, or Dr. Berry, were in agreement with that. They said they would like to, but at the same time under cross-examination I tried to find out just where and how much and how soon and when should we get started.

I was unable to do that. I was unable to get a handle on it, so to speak. So I don't know that you and Dr. Adey are in any great disagreement on that score.

(Dr. Warren nods.)

Mr. KARTH. I think he did say that the results of certain fundamental experiments on the primate could be extrapolated. On the other hand, the General said nonsense, you know, it is just impossible, it couldn't be done.

(Dr. Warren nods.)

Mr. KARTH. Now, I was just wondering which of those two statements, if they be in the extreme, you would find yourself closest to?

Dr. WARREN. Well, I suppose I would be closer to Dr. Adey on that, although I am not so sure that the others are really far different. They have in effect a sort of corporate responsibility of the Office of Manned Space Flight, which is dedicated to that position in part.

Mr. KARTH. Well, it is obvious that you feel that the agency, as such, has done a poor job on an overall basis in the biomedical research field, if you are in agreement with the report that you recently filed with the President.

Dr. WARREN. I am.

Mr. KARTH. Isn't that correct?

Dr. WARREN. That is correct.

May I just add one additional point to that? We talk about things going from animals to man. There are some interesting biological points that go the other way. For example, there has been great interest in some things that have happened to the red blood cells of the astronauts. There is still debate as to the mechanism and the degree of the untoward effect, but this has stimulated laboratory researchers, indeed at our own laboratories at Ohio State University, to do experiments on animals, trying to solve this.

And I think the interesting sort of spinoff in a scientific way is that they are finding out some things about red blod cells that they would never have thought of before and that in some vague way, I can't be specific, this may help us eventually as physicians in treating the ills of human red blood cells on the ground.

Mr. KARTH. Didn't this occur when 100 percent pure oxygen atmosphere was being used?

Dr. WARREN. This seemed to be a primary factor, but what I am referring to is the scientific effort at unraveling why this happened, and I think this would be classified in the group of medical things that are spinoff, if you will.

Mr. KARTH. I would think so, since on many occasions, I guess, when one is critically ill, they are put in essentially 100-percent pure oxygen atmosphere, are they not?

Dr. WARREN. That is correct.

Mr. PETTIS. Mr. Chairman.

Mr. KARTH. Mr. Pettis.

Mr. PETTIS. We have some physicians, at least one, I think we still have one physician in the astronaut program, do we not? I mean as an astronaut, or am I wrong in that?

Mr. KARTH. An astronaut who is a medical doctor?

Mr. PETTIS. Who is really a medical doctor.

Mr. KARTH. Yes; we do have, I understand.

Mr. PETTIS. Why wouldn't it be possible, not on a lunar mission, but on something short of a lunar mission, to have a physician on board to conduct some indepth studies, some implantations and those that would be short of the need for a hospital situation.

Dr. WARREN. I think it would. I think there are several points about this that might be commented on. One is that my impression, and recognize that I am not down at Houston and am not really close to this, is that the early physician astronauts, although they were physicians by training, were not physicians who had a sizable research experience, which is, I must say, different from being a physician, and second, their time in training was so involved in really becoming an astronaut that by the time they are ready for space flight, and they are not apparently ready yet, they are more astronauts than they are physicians.

Mr. PETTIS. But do you really need that highly trained a physician to perform the technical aspects of implantation and readings and so on, to give back to you men on earth who have a great deal more expertise than the physician astronaut might have?

Dr. WARREN. Yes: I would think so. It is just like taking a pilot who trained on a DC-3 and suddenly ask him to fly a Boeing 707. I think we are moving along in medical instrumentation, partly thanks to the space program, very rapidly, and I think he would have to be kept up to speed and would have to be a true participant in the research program.

And I believe—and I am now quoting what I read in the newspapers—that some of the dissatisfaction among the scientific astronauts has been related to the fact they have been unable to remain competent in their field of choice, that they have been so busy really becoming an astronaut.

And I think, though, on the other hand, on the point you made, and indeed I think way back when I was on the committee that wrote this volume here, "The Medical Aspects of an Orbiting Research Laboratory"—it is now about 5 years, I guess—we projected at that time that there would be physicians functioning in the very way that you described, and I still think this is quite a realistic possibility.

It will take, however, again, long-range planning in design and so forth of the space vehicles to accommodate the medical program. And to some degree, maybe less so now than in the past, the design has been, as it should be, primarily aimed at getting the vehicle where it wants to go and back again, that biomedical considerations have not been high on the priority scale.

And I am just saying that now we have progressed this far maybe we should get biomedicine higher on the NASA priority scale.

Mr. PETTIS. If I may, Mr. Chairman, just pursue this a little further.

Mr. KARTH. Yes.

Mr. PETTIS. These vehicles aren't as small as they used to be and they seem to be quite commodious. I was wondering if we couldn't maybe leave off some of the things that we take aboard; these packages, we call them packages, and substitute some of the things we have been talking about this past week.

Now, I don't know, maybe I am wrong, but it wouldn't seem to me that it is any more traumatic to perform some of these implantations on an astronaut than it is on a monkey, particularly when you have two other men on board to handle the technical side of keeping this vehicle on course and so on.

Dr. WARREN. I think that is basically correct, and that is the way things are planned. I would point out one always worries in putting

instruments inside a person, to generalize in that way, about the accidents that can happen, a catheter up a vein or an artery can perforate it in a very small number of instances, and would they be able to cope with those emergencies.

These are considerations that obviously have to be worked out, but it is my understanding that really the planning is that in the orbiting laboratories there will be facilities for biochemical and physiological studies, the so-called IMBLMS program that General Humphreys talked about, is a step in this direction.

Mr. SYMINGTON. Mr. Chairman.

Mr. KARTH. Mr. Symington.

Mr. SYMINGTON. Following on Mr. Pettis' question, are you suggesting that it may be too dangerous to seek the information from astronauts in flight that we would actually need to insure their safety in further flight?

Dr. WARREN. I think at the present time on many of these penetrating methods—you understand what I mean by that—the answer would be yes. But looking further forward, when we have a larger, better-equipped orbiting laboratory, then I think we can do more. Nevertheless, I feel, my own feeling is, and I think there are others that agree with me, that when we have that laboratory, there is also still going to be some very fundamental programs that would need investigation by means of animal studies.

Mr. SYMINGTON. If we knew precisely what kinds of instrumentation we would like to experiment with on man in space, and yet we weren't sure of the safety of applying them, wouldn't it be a good idea to try them here in a simulated environment first, just to see if it was safe to try them out in a weightless—outside of reentry problem?

Dr. WARREN. Quite true, and indeed this is as I see it one of the major thrusts of the PSAC biomedical report, that if you see the phrase "qualifying man for flight to Mars," it will require a long-range period of study and much of this study will be ground-based.

The point I would make is that we have not made as good progress on that as I would like to have seen. And then, of course, the next question is why not, and I think there are several reasons. I think the scientific community of the country has not been involved to a great degree in this, and as I pointed out, the number of biomedical scientists doing really fundamental research of the type you talk about at Houston is almost negligible, and we just haven't?

Mr. KARTH. Would you restate that, Doctor?

Dr. WARREN. I think at the Manned Space Flight Center in Houston that the number of people who are at work in that large complex doing fundamental biomedical research is very small.

Mr. KARTH. How many are there?

Dr. WARREN. I should qualify that in addition, that there are many people there working on equipment and who are working on the observation of the astronauts in the flight surgeon type of role.

Mr. KARTH. How many are there of those?

Dr. WARREN. I can't give a number. I am sure that some of the NASA friends could do this.

Mr. KARTH. You feel there is a gross disproportionate number?

Dr. WARREN. I think there are too few people working closely in cooperation there on basic biomedical research. Now, I don't want

to say that there are too few or too many doing the other jobs. It may require a lot of people working on equipment. But I will just say as an absolute number it seems to me——

Mr. KARTH. But at any rate that is where the emphasis is?

Dr. WARREN. Yes. It would seem to me there are many patterns of improving this. There are other installations, such as the Atomic Energy Commission, where there are biomedical—at the Brookhaven Laboratory on Long Island, where there are biomedical scientists from many universities participating in the program and the facilities of Brookhaven.

And it seems to me that real efforts ought to be made to get more people involved in fundamental biomedical research, involving various aspects of the space program.

Mr. KARTH. Another question. Do you think it is essential that these people be brought into NASA, as NASA employees working at the Houston Manned Space Flight Center or elsewhere, or do you think that most of this work ought to be done at the universities and other places like it?

Dr. WARREN. I think much of it could be done at the universities. If it is done at universities, it has a side benefit that as a medical educator I consider very important. It is done where we are training people in various aspects of biomedicine, and therefore it will have sort of a double dividend.

On the other hand, there are certain ground-based experiments related to the space program that could only be done at places like Houston, where the very complex and expensive facilities exist. But I would foresee the possibility that a scientist wouldn't necessarily have to be an employee of NASA, that he could come there on some leave of absence or something from his university to do a series of experiments utilizing such an item as their large human centrifuge.

Mr. KARTH. Thank you.

Mr. SYMINGTON. Thank you, Mr. Chairman.

I take it that you have said that there is certain information which we would like to have concerning the effect of space flight on astronauts which we do not now have, and couldn't have unless we could perform certain instrumentation, and we are not too sure that it is safe to give them that kind of instrumentation.

We have managed to successfully return astronauts in pretty good health after 14 days. How long would you like to see them flying in space before you had this information, in advance of the next extended flight?

Dr. WARREN. I think this is, of course, the advantage of the incremental approach. You get to look sort of a short distance and since you know they do well in 14 days, the evidence would indicate that at say twice that, at 28 days or something around that, they probably would continue to do well, but you would like another point on the curve before you extrapolated further.

And the point I was making earlier relates to the fact that as I look ahead by continued extrapolation, trying to look ahead to Mars, I think that we need a totally new capability of extrapolating there, and this again refers to what I consider another major part of the bioscience report of PSAC: namely, that we need to create a, it is almost a new subdiscipline of biomedical science, of expert in this field who will

develop new techniques and who will hopefully enable us to project forward at much longer lengths in time and give us a greater degree of certainty.

It would be a shame if we as a nation decided we wanted to send a man to Mars and indeed mounted the whole expedition and then found out that man really just couldn't tolerate this. I would point out that much of the discussion today has related to the heart and the circulation and the bones, but when I think of such long flights I think the psychological fatcors of being away so long are equally important and equally need investigation.

Mr. SYMINGTON. You have suggested that to prepare for a Mars flight you would need almost an entirely new magnitude of biomedical information and the ability to get it. Now, when is the window for Mars that we are first looking at? Is it 1981?

Mr. KARTH. About that.

Mr. SYMINGTON. 1981.

Dr. WARREN. About that. I don't know exactly.

Mr. SYMINGTON. If you were in charge of the whole program to send a man to Mars in 1981, when would you start constructing this new biomedical apparatus?

Dr. WARREN. About 5 years ago, I guess.

No; seriously, I think we should start it soon. And the only question, or point I would raise about your last comment was that I would not think that this would be an enormously expensive new venture, that it would mean reorganization of the NASA biomedical program, and it would mean certain new activities, but much of these would be ground-based and therefore wouldn't be in the fantastically expensive area that many new boosters and so forth occupy.

Mr. SYMINGTON. So we could even achieve this necessary expertise at a reasonable cost, and yet as far as we know we haven't made that commitment, in spite of our interest in going to Mars by 1981.

Mr. KARTH. Would the gentleman yield?

Mr. SYMINGTON. Yes, sir.

Mr. KARTH. How many years, Doctor, of this type of indepth inquiry or research do you think is necessary before we can design with any assurance a Mars flight-type vehicle, beginning now? We haven't done any of it, so let's start right tomorrow.

Dr. WARREN. I really don't know.

Mr. KARTH. What is your best guess?

Dr. WARREN. I would guess that this would take 5 or 10 years, to do the necessary research, but I am just making a wild guess at that.

Mr. KARTH. Do you know of anyone else who has made a guess at it?

Dr. WARREN. No; not specifically. I think some of the discussion in the biomedical report referred to implications in this order of magnitude.

Mr. KARTH. Thank you.

Mr. SYMINGTON. Could we say then that if a crash effort were made today to learn enough about the effect of weightlessness over long periods on man, we might just barely make the deadline of a 1981 flight?

(Dr. Warren nodding.)

Mr. SYMINGTON. So while all of the systems being created for that flight were being built, one great unanswered question would be can man take it in those systems?

(Dr. Warren nodding.)

Mr. SYMINGTON. And with everything all ready to go and the smoke billowing out, somebody might come up with a message saying, "You can't, don't shoot."

Dr. WARREN. It is possible.

Mr. SYMINGTON. That would be a fair statement of your position?

Dr. WARREN. I think that could happen; yes. I think that the hope would be that in a shorter period of time, at least a reasonable answer enough would be obtained that we could go ahead with the planning of the hardware, and so forth. Of course this has been the problem all along in the space program, it strikes me, as a nonparticipant, and that is the difficulties created by the very long leadtime in hardware and construction of the equipment.

This has been one of the factors that has, I think, stifled to a degree biomedical participation. We have talked a lot about Dr. Adey, and I would just like to comment that Dr. Adey as best I can see has devoted the better part of several years of professional life to his participation in the biomedical program, and an awful lot of this funneled down on that one primate.

Now, fortunately, it hasn't been totally. There have been other activities. But this is very demanding, and therefore it is going to be the unusual scientists who will give this much to this program.

Mr. SYMINGTON. Dr. Adey's testimony, as I recall, was not so much that we knew enough from the primate's flight that we could anticipate certain things, but that the experience of Bonnie gave great reservations to him about the possibility of encouraging even on a 28-day flight and that he would have hoped that we could experiment more, as you have suggested, with primates. I take it you do agree with that.

Dr. WARREN. Yes.

Mr. SYMINGTON. That is all I have.

Mr. KARTH. It is kind of an unusual scientist who is well known, as eminently, I think, as Dr. Adey is—it is kind of unusual for a scientist of that kind to stick his neck out, isn't it, put his neck out on the line, so to speak, like he did. He must feel very strongly about this thing. But nonetheless it is unusual for a scientist to do what he has done in coming to the conclusion that he has come to and the testimony he has given to this committee, is that a fair statement?

Dr. WARREN. I would think that is correct, yes.

Mr. KARTH. You said that a good deal of this research that needs to be done before we can make a reasonably sound judgment as to whether or not man can last for 2 years in space, vis-a-vis Mars flight, can be done on the ground, didn't you?

Dr. WARREN. Yes, sir.

Mr. KARTH. Is that in contradiction to what the two witnesses this morning said? It seems to me that they implied strongly, or said emphatically, that that had to be done on man in space under actual flight conditions.

Dr. WARREN. Well, I think it relates to one's direction in looking at the question. I believe what I just said, that much of it could be done

on the ground. On the other hand, the one thing that you really can't simulate on the ground is the matter of zero gravity. So that does become in the final analysis the critical factor.

But the point I would make——

Mr. KARTH. It is a relatively critical experiment, isn't it, Doctor?

Dr. WARREN. Yes. But on the other hand many of the things, related again, if we use the Mars flight as example, the confinement, the other aspects of that, the atmosphere, for example, there are things that we can study on the ground.

Mr. KARTH. Yes; I would assume that there are some things, and it might even be a majority of things. I wouldn't quarrel with that. The reason I asked the question is because, No. 1, we are not going to have any reasonably long inspace manned flight until 1972 and 1973. That is 2 and 3 years from now.

I don't know whether or not the plans are sufficiently well laid at this point to give us a good indication of what kind of experiments are going to be conducted on the astronauts and how that relates to long-term weightlessness. But assuming that some reasonable effort was made in that regard, by the time the flights were completed, by the time all of the results were in and evaluations were made and judgments and recommendations accompanied them—we are talking about 1974, perhaps, or maybe even 1975.

Now, that is just a 56-day flight at maximum. Would you suggest that it has to be much longer flight time than that for man to make, in which there is substantial experimentation, before we can make the judgment as to whether or not we could go to Mars?

Dr. WARREN. I think—the thing that I am saying is that we need sort of a whole new area, a whole new ability to think out these things, a new device to determine these points, and that is why we are all sort of floundering with them at this time.

Now, I would personally think that we would feel more secure if man had experienced longer than a 56-day flight, before we sent him off on the long trip to Mars. This could be relatively easily obtained, or an orbital laboratory.

Mr. KARTH. You don't really think with 56 days' experience we could send a man on a 2-year mission, do you, Doctor?

Dr. WARREN. I think we would be very reluctant to be that, yes. I think we might be able to do it——

Mr. KARTH. Under the circumstances, it is really impossible to really think of a 1981 or 1983 timeframe, isn't it, even if we went all out from this point forward almost on a crash basis?

Dr. WARREN. A few years ago I heard the point made—I think I can quote it correctly—that if you take all of the cardiovascular literature, the medical, the scientific reports about the heart and blood vessels, going back to William Harvey and so forth, and you took the midpoint in that output in terms of numbers, that the midpoint would come out something like 1957 or 1958. In other words, as many articles have come out since 1958 as in all of our past experience before then.

And I think the same thing is going to happen in the future. So it is hard to predict. And I think it is conceivable, though, with various types of systems analyses and so forth, that we might develop a way, and this is what I would search for, a way to predict better than we can now.

This is what we desperately need. So this predictive ability would be the real goal.

Mr. KARTH. But you really don't think we can do this using animals; you really don't think we can extrapolate to any great degree by the use of animals and implantations and other experiments that will for any number of reasons be difficult to do on astronauts?

Dr. WARREN. I think it would help, but I think, again, unless we have some new dimension in making these predictions, that knowing an animal had gone 120 days, for example, would not convince most people that man was capable of doing that.

Mr. KARTH. Or 240 days or something. You see, if this is relatively insignificant, we are not going to spend the money, you know.

Dr. WARREN. Yes.

Mr. KARTH. Because after all it is really going to contest the question whether or not man is physiologically and psychologically fit for long duration that puts a question on it.

I think you hit the nail on the head. I think it is the Mars mission that really all of this debate is centering on; in good part it is the Mars mission or other interplanetary missions.

Whether it is expensive in terms of Apollo program costs or not, I am not so sure if it is relatively insignificant and unimportant that we ought to do any of it, to tell you the truth.

Dr. WARREN. You notice I always qualify "if we make the decision."

Mr. KARTH. Because I don't really care if animals live in space or not. I would hope we would not start a barnyard on the moon or anyplace else. I really don't think it is important we raise young chicks up there, if it really doesn't have considerable significance to the well-being of man.

So if the scientific community is going to equivocate about this on the basis of their friendships, or that their association with one person has to be maintained, and at the same time they don't want to offend anybody else, then of course this committee is going to have to accept it as factual evidence that we really can't use primates or other animals and extrapolate from those experiences what the effect on man would be.

Dr. WARREN. Let me try to put it in just one other way, that it means to me that if you are thinking about sending man to Mars and want to have the biomedical backing for this, you really have two paths open. There may be some others but I see two.

No. 1 is a continuation of today's method of sort of incrementally studying man's performance and moving him up a notch each time. That is what we have done. And based on that we have done pretty well, at these shorter flights.

The other alternate is to say there must be some better way to do this prediction and to set out with a very fundamental attack on prediction of devising a new approach to prediction. And it is the second method that I would think would be most attractive.

Now, I feel that way not so much because I think it might be more likely of success but it isn't a dead end that we are spending a lot of money to do. I think we are going to learn more—every doctor wants to know how to predict the outcome of his patient's ills.

It is an area of biomedicine that I think needs further study anyway. So that is why I have some more enthusiasm for that. I think the other——

Mr. KARTH. This new trend of experimentation, Doctor, is going to take place either on animals or it is going to take place on human beings, if we are talking about living things; isn't that correct?

Dr. WARREN. Right.

Mr. KARTH. So I am not so sure that we can't make that decision now. You say some new method——

Dr. WARREN. I didn't make it clear, I guess.

Mr. KARTH. Oh, I misunderstood, sir.

Dr. WARREN. With a new—now inconceivable to us—method of analyzing short-term data on either animals or man, I would be, or we would be better able to predict what the long-term result would be.

Mr. KARTH. I see.

Mr. MOSHER. Mr. Chairman.

Mr. KARTH. Mr. Mosher.

Mr. MOSHER. I am just a little troubled by something you said a moment ago, Mr. Chairman. You wouldn't want us to be saying that the only reason for biomedicine in space is to determine whether or not man can go to Mars. Aren't there many reasons for a very active biomedical space program simply because space is an environment in which we can learn a lot about biology and medicine and there are many, many uses here on earth for the results of such experiments?

Mr. KARTH. Oh, yes. We are really talking about the manned bioscience program. That is really the subject of this inquiry. I agree with the gentleman from Ohio and Dr. Warren, that in addition to that, we should have a bioscience program.

Mr. MOSHER. Yes.

Mr. KARTH. But that is, you know, like apples and oranges, Charlie.

Mr. MOSHER. OK.

Mr. KARTH. That is the argument I don't want to get in with you, because I agree with you. We are talking really——

Dr. WARREN. Right.

Mr. KARTH (continuing). About this bioscience effort and its relationship and importance to the manned space flight program, and whether or not we ought to do more to enhance the success of the manned space flight program for the future, or whether or not it is even important to consider it.

Mr. SYMINGTON. Mr. Chairman, just some short questions.

Mr. KARTH. Yes.

Mr. SYMINGTON. Dr. Warren, you mentioned that if a primate lived 120 days in space, that this would not convince you, I take it, that a man could; that you would not be totally reassured about a manned space flight of that duration. Did you say that?

Dr. WARREN. Yes. I think it would go a long ways toward convincing me.

Mr. SYMINGTON. Yes.

Dr. WARREN. But I don't know that I would use that as the only basis.

Mr. SYMINGTON. Right; yes. On the other hand, if he died at the end of the 10th day of a projected 4 months' trip, that would give you some concern?

Dr. WARREN. Correct.

Mr. SYMINGTON. Since it would give you some concern it means you do extrapolate from the experience of the primate?

Dr. WARREN. Maybe part—yes, I would. But may I just say maybe part of the controversy, if that is it, about this experience with this primate relates really to the use of the word "extrapolate." I can take that knowledge and apply it to man. I don't say that the monkey died in 10 days, therefore man is going to die in 10 days.

Mr. SYMINGTON. Well, perhaps we should do away with this word, because if that is what it would convey then none of us should be using it.

Dr. WARREN. Yes.

Mr. SYMINGTON. But you would apprehend difficulty to mean if the monkey died, and you wouldn't know where to expect that difficulty but you would be darn sure looking for it?

Dr. WARREN. Correct.

Mr. SYMINGTON. And therefore you would like to have something to look for. You would like to see the primate make the trip, so you could at least decide whether or not man should fear something in particular and whether a supportive system should be designed to compensate.

Now, finally, you said in the scientific community you were somewhat floundering for the answers. But I got the impression this morning that General Humphreys was not floundering. He set his course like the northern star and he has no apprehensions at all.

Do you think perhaps he should be more sensitive to the opinions of the scientific community which you represent, and which I take it Dr. Adey represents, that to share those apprehensive would be beneficial for him in the decisions he has to make?

Dr. WARREN. Yes. I think this is part of what we are saying, in the biomedical report of PSAC; that these problems are progressively getting tougher. One of the most desirable things would be a new device, either a thinking device or a hardware device, to make them easier.

In the absence of that, in trying to find them, we think that this calls for everybody getting their heads together and trying to make a major push out of it. This requires a sizable commitment. I must say that there are many of my colleagues who feel that there are other commitments more important. I don't need to tell you gentlemen this.

Mr. SYMINGTON. You say sizable, but didn't you say earlier not necessarily costly? Is it, what, psychologically sizable but financially not so bad?

Dr. WARREN. I think—well, there are people of course who question the current commitment, obviously, for whatever internal use it is aimed, but if one says that we are going to have a space program, then it would seem to me that really a biomedical program of the type described in the PSAC report is in a sense really just insurance against catastrophic losses in the space program.

Mr. KARTH. Would the gentleman yield?

Mr. SYMINGTON. Yes, sir.

Mr. KARTH. Aren't you really saying that it is costly in terms of time, more so than money and techniques; and it is going to take a long period of time to find answers to these questions that necessarily, in your judgment, must be answered?

Dr. WARREN. I would agree with that and would add one more cost, and that is a really expert biomedical talent.

Mr. Karth. Yes.

Dr. Warren. Medicine on the broadest of fronts being asked to do a lot more today than they were 10 years ago. We just don't have enough trained people to do all of this.

Mr. Karth. And a good deal of this, if done in the universities and some of the other Government installations, could be pretty much bought for free; couldn't it?

Dr. Warren. Well, I don't know it would be free, but I think it would be——

Mr. Karth. Bought fairly cheaply.

Mr. Warren. Considering a scientist doing something in an isolated NASA laboratory would be less rewarding to the country than having him do it in a laboratory say in a teaching institution, where he has graduate students and other people about him that are profiting from this experience, and that in turn that would add experienced man-hours to the program.

So it would seem to be a mutual beneficial device.

Mr. Karth. Mr. Symington.

Mr. Symington. That is all, thank you, Mr. Chairman.

Mr. Karth. Do you have any questions?

Mr. Hammill. No.

Mr. Karth. Do you have any question?

Mr. Dickinson. No.

Mr. Karth. Is there anything that you would like to add, Dr. Warren, to what you have already testified to?

Dr. Warren. No, except I would just say that these problems are difficult, and I worry that we try to specify numbers—would fly it after 120 days. Well, everybody has problems with these. I think I would like to see that the NASA organization had the best possible, the broadest possible group of people making these decisions, and that it would be better to have that than having one group handle the animal experiments and another group relatively isolated handling the human studies.

It seems to me a reorganization at no change in dollars would be of benefit.

Mr. Karth. Some of us have suggested that as long as 3½ years ago, Doctor. If you think it is difficult for you and others to make these judgments, and indeed it is, just imagine how difficult it is for this committee.

Dr. Warren. I sympathize with you.

Mr. Karth. And it is difficult for Congress to make these decisions, when we have very knowledgeable and very reputable and really able people disagreeing on what the approach might be; disagreeing, perhaps, just because of the way they have been taught to do things or the way they have grown up doing them, maybe in the last 5 or 6 or 7 or 8 or 9 years, which causes them to arrive at certain judgments—rather than calling upon their real professional background per se, exclusive of all other interests, what that might do if they did that in terms of maybe giving them a different position and providing this committee with additional information—all of which might make it easier for us to make a decision.

But it is very difficult indeed for us to do that, particularly I think, since there are so many who really refuse or at least fail to be as candid

as we would like to have them be for any number of reasons that they might find important to them.

So it is a difficult process that we go through. It is not really fun for Mr. Symington and the chairman to almost approach the position of being less than respectful of the witness. It is not fun, it is not exciting to me at least, I don't find it invigorating to do that, and I don't think any of the other members of the committee do, either.

Nonetheless if we are going to be saddled with the responsibility of making a decision in concert or without the cooperation of the administration, whatever it might be—being two branches of the Government that have decisionmaking authority in this field—we feel we would like to make the decision on the very best evidence we could get.

That might be old fashioned but at least it is this committee's intention to make the decision on that basis, even though it involves a rather disagreeable work for us to try to come to those conclusions.

So we appreciate your assistance to this committee. We would like to invite you to submit any further testimony that you would like to submit and cover any questions that we for any number of reasons might have failed to ask you, or cover things that you for any number of reasons might have failed to give today.

Dr. WARREN. I would like to do that. I have given Mr. Dickinson one little piece of spinoff information about the use of telemetry in a mobile coronary unit. I would just like to say that as a citizen and no more than that it is reassuring to me to come to Washington and find out that these matters are being so carefully pursued, and I really appreciate the opportunity to speak my piece, but also to get a postgraduate education in civics.

Mr. KARTH. Well, we are most grateful to you, Doctor, for coming. We have made arrangements, I think, for you to get to the airport.

Dr. WARREN. Very good.

Mr. KARTH. We are most grateful. Thank you very much. The meeting is adjourned.

(Whereupon, at 3:34 p.m., the subcommittee was adjourned.)

(Pursuant to the invitation of the chairman, further comments were submitted by Dr. Warren, as follows:)

THE OHIO STATE UNIVERSITY,
DEPARTMENT OF MEDICINE,
Columbus, Ohio, November 19, 1969.

Hon. JOSEPH E. KARTH,
Rayburn House Office Building,
Washington D.C.

DEAR SIR: It was a privilege to appear before your committee on November 17. On thinking over the hearings on my way home, I decided to accept your invitation to submit an additional statement, in the hope I may be of some value in interpreting the remarks that your committee heard during the past several days.

I sense that you and your committee have felt that the medical profession and the biologists have not really been in internal agreement about many of the matters under discussion. It would be my feeling that the area of disagreement, if that is the correct word, is not as great as it might seem. The facts are as follows.

1. The number of scientific observations on man and animals in space is limited. All of the witnesses have essentially the same data before them. Some may have studied it in greater detail than others but really the data base on which we are commenting is essentially the same and available to all.

2. With the meagre facts available, no one is truly an expert. The facts are so few that they fit a variety of interpretations. In particular, the predictions or the guesses about what is to happen in the future vary with the individual. For example, there is a football game between Ohio State and Michigan this Saturday. Some "experts" and the odds makers say that Ohio State will win by 15 points. Some partisans here at Ohio State say that it will be no contest, others feel that Michigan might win. A hearing would only reveal this range of opinion and not really give the "answer". Equally, men vary in their opinion about the projections from these few data points about man in space.

3. The greatest worry I have about your hearings is that, in taking these bits of data to a variety of people searching for an "answer," you'll find that you are just finding out that a group of people vary in their firmness of conviction regarding an uncertain group of facts, just as the famous blind men did about the elephant. Some people will take a stronger stand than others. This doesn't necessarily mean that some are better informed than others but rather it's an expression of a variation in human behavior. It would seem that there are few solid conclusions which can be made from the few bits of data that are now available. A point that I tried to make at the hearing was that, especially in biologic research, multiple data points are required. One or two kidney transplantations don't indicate the prospects of this procedure in the future.

4. A major thrust of the PSAC report was that, by doing business in the current and conventional way, it is unlikely to produce a reliable ability to predict such things as man's tolerance to space. It was, therefore, the recommendation of the panel that a totally new look in the biologic problems of space be taken. This isn't to say that the people who have made the observations so far haven't done their job well but it just says that it isn't giving us the answers that all of us want and, therefore, we should look for another mechanism of definining the answers. We really don't know that this can be done but until a coordinated attack on the problem is made we can't say that it can't be done.

5. One of the contributing problems so far in the space program is that the engineers and non-biomedical people have had some of the same difficulty that apparently your committee is having, namely, inability to get a hard and fast answer about a problem in biomedicine from a few observations. Because there was this apparent uncertainty, especially as compared with some of the physical science observations. biomedical experiments have suffered and have been deleted by the engineers who have been in charge. A further point, therefore, would be that the evaluation of what is to fly and what is not to fly should not be totally in the hands of one disciplinary group or another. We feel that biomedical considerations rank high on the priority scale at this time. I am sure that some would consider this a partisan view, and it may be, but on looking at the broad picture of the space program, the biomedical problems are critical from an operational sense as well as from the standpoint of potential scientific reward from the space program.

6. Obviously other information and questions are involved in the hearings. The points covered in this letter represent only one component.

I am confident that many of my biomedical colleagues feel that the questions raised here are the source of confusion at times. We realize the problems of evaluating such considerations and sympathize with you in the complexity of the job that your committee has undertaken.

Sincerely yours,

James V. Warren, M.D.,
Professor and Chairman,
Department of Medicine.

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THE FUTURE OF THE BIOSCIENCE PROGRAM

TUESDAY, NOVEMBER 18, 1969

House of Representatives,
Committee on Science and Astronautics,
Subcommittee on Space Science and Applications,
Washington, D.C.

The subcommittee met at 10:12 a.m., in room 2325, Rayburn House Office Building, Hon. Joseph E. Karth (chairman of the subcommittee) presiding.

Mr. Karth. The committee will be in order.

Today we continue our hearings on the future of the bioscience program with spokesmen from two distinguished agencies—the American Institute of Biological Sciences and the National Academy of Sciences. We are privileged this morning to have as witnesses Dr. Lamont C. Cole, Cornell University ecologist and president of the American Institute of Biological Sciences; and from the National Academy of Sciences, Prof. Loren D. Carlson, chairman of the Division of Medical Sciences, School of Medicine, University of California at Davis and who also is a member of the Space Science Board of the National Academy; and later on this morning, Prof. Donald Farner, chairman of the Department of Zoology, University of Washington, Seattle, who is also chairman of the Division of Biology for the National Academy of Sciences.

We are very happy to have you with us this morning and we wish to invite you to give whatever testimony you deem to be necessary for furthering the purpose of the hearings.

Who would like to be heard first? Dr. Cole.

Dr. Cole. All right.

Mr. Karth. Would you proceed, please.

STATEMENT OF DR. LAMONT C. COLE, CORNELL UNIVERSITY ECOLOGIST AND PRESIDENT OF THE AMERICAN INSTITUTE OF BIOLOGICAL SCIENCES

Dr. Cole. I don't have a prepared statement, and I guess I am here really representing a segment of the biological community. I can assure you that I am completely uncommitted and unbiased as far as the manned space program goes and the biosatellite program; so I think I can at least discuss this objectively.

Mr. Karth. That is the best news I have had this morning, Doctor.

Dr. Cole. As an ecologist, I think I lean a little bit toward manned missions, simply because I hope it will make our policymakers and the public realize when they do come to understand the difficulty of

putting together a life-support system that is going to work for a long time, I hope it will give them a new appreciation of the marvelous life-support system we have here on earth and perhaps start thinking about taking risks with this one.

There are a few basic biological phenomena that can be studied best in space and predominant among this, as a lot of your previous testimony has shown, is weightlessness. This is something we can't simulate for more than a few seconds on the earth's surface; so we really don't understand what is going on in many biological systems and in particular in the physiology and embryology.

I think this did contribute very fundamental knowledge to some basic biological processes, and I am sure Dr. Carlson can say much more than I about the physiological implications of this.

There are, of course, other reasons for wanting to get men out in space, such as the matter of getting a telescope out where it is not obstructed by the earth's atmosphere, which can lead to very fundamental advances in science.

So, if you are serious about doing this sort of thing, or continuing space exploration, we are going to have to find ways of making it possible for man to spend prolonged periods in space. So I think it is extremely important to gradually lengthen the durations of space flights and find out just what adjustments may have to be made, whether we are going to have to simulate gravity or just what is going to have to be done in order to make this possible; and conceivably it is impossible for a man to tolerate weightlessness for prolonged periods.

Also, in the space program, as an ecologist interested in the way life evolved and how it got that way, there are some very basic questions of the evolution of life and the evolution of organic matter prior to the origination of the living condition that might be answered by space exploration.

I published a letter several years ago in Science expressing the hope we would not shoot rockets to Mars or Venus until we were ready to put a man there to look for evidences of life, because conceivably there could be forms of life so very different from anything we are familiar with that our automated systems would not be able to detect it.

I raised the question out at the Manned Space Flight Center a year ago as to whether they were looking for evidences of life that had the symmetries of the amino acids and proteins reversed from the way they are in earthly organisms and, no, they weren't even planning on this sort of thing. This could answer a very basic question as to whether the peculiar symmetry of organic molecules we know here on earth is an accident, that life on earth got started that way, and we have all inherited this condition from the first forms of life, or whether it is possible that there is some basic asymmetry in the universe that makes other types of life impossible.

So all of us would be extremely interested in any evidence of life of any sort occurring on Mars and to look at these molecules and see whether they are the same types we have.

Also, we now believe that organic matter evolved long before life evolved, and it wasn't until a nucleic acid came along, some molecule with the ability to duplicate itself, that we got a possibility for evolution and giving rise to all of the great variety of living forms we have now.

So I also worried that if Mars should be back in this prelife condition, this so-called primordial soup, we might contaminate it and it might not take a living thing to do this. A dead micro-organism might carry enough DNA, nucleic acid, to set off evolution like that here on Earth, and at the moment, Mars appears to be our single really good hope for finding life or prelife in the rest of the universe.

Also on this space program, I am very much impressed with the spinoff of apparatus. I realize that these research devices for remote sensing and the very miniaturized spectrometers, and amino acid analyzers, and so forth, could have been constructed without any space program, but they weren't. This gave the impetus to make an amino acid analyzer small enough so it didn't have to fill a room, and I am very happy to see this sort of development coming along, and I believe this spinoff is going to provide us with a lot of instrumentation that will be useful in other connections.

I have talked to the physiologists out at Houston about the possibility of setting up unmanned monitors to monitor pollution in environments here on earth, and I think they have a technology that can prove to be extremely useful to us in this connection.

There is one other factor we can't simulate on earth. It is of rather basic importance, and this is the matter of getting away from the earthly periodicities that are possibly tied in with the rotation of the Earth and its annual trip around the Sun and also, of course, the 28-day revolution of the Moon.

Biological systems do show these periodicities, ranging from the circadian rhythm on the order of 24 hours to much longer ones. We don't know to what extent these are conditioned by environmental changes in the flux of cosmic radiation, and so forth, and to what extent these are simply built into the biological system.

So, getting away from the earth's influence in an environment where you are away from all the earthly periodicities, will give us the possibilities of studying these things, throwing an entirely new light on the nature of these periodicities.

This is possibly going to be of great fundamental importance. Although I don't know if it is justification for an extremely expensive program, it is certainly one thing we can hope to learn as a result of this program.

Finally, I would simply state that AIBS, American Institute of Biological Sciences, has been furnishing consulting committees to these bioscience programs in the Office of Space Science and Applications; so there has been cooperation of the biological community into this whole system.

I think that is all I care to say at this time. I would be happy to try to answer any questions.

Mr. KARTH. Are you at all familiar, Doctor, with this recent report of the Space Science and Technology Panel?

Dr. COLE. I glanced through it very rapidly. I didn't receive a copy.

Mr. KARTH. As you glanced through it, did you find anything you might object to, or did you find yourself mostly in agreement, particularly as it applies to the recommendations that the committee made?

Dr. COLE. I am sorry. I must have glanced through it too rapidly to recall the recommendations.

Mr. KARTH. I don't know if I want to take the time to read them to you, but I think that one who has a deep interest in biological development, as I know you do have, these recommendations would be of interest to you.

I think the essence of what they recommend is that we have a much more aggressive biomedical, biological research program, and that that investment, of course, include whatever substantive needs are required on earth here and in space, so that we can make what they consider to be at least the proper experiments. They feel rather strongly that the manned space flight program, up to this point, has not really done this, that they have overlooked the need or the importance of this kind of a broadly based biological research program in their haste to get to the moon and to proceed with other engineering development programs.

So in this PSAC report they recommend a very broadly based and energetic program in the area I mentioned. That basically, I think, is the recommendation of the committee of scientists. In their findings, they make quite a point of the fact we don't really have a base of this sort in the Nation today. NASA doesn't have a base. The United States doesn't have a base of this kind, of the kind necessary. They feel that the universities and some of the existing Government installations in the country could assist greatly in this regard. They feel, I guess, that man ought not serve as the guinea pig or at least he ought not to serve as the only guinea pig. That basically, I think, are their recommendations.

Would you agree with that?

Dr. COLE. Yes. I can make several comments on that. I get the feeling from everyone I talk to that there is a need for more coordination within the space program, that there are several groups operating almost independently and not communicating very well, and that communication with the academic community is not what it should be.

I also get the feeling that some of the biologists are unhappy with the extent to which the engineers and the physical sciences are dominating the program.

Mr. KARTH. Are you unhappy about that?

Dr. COLE. Yes; I am unhappy when engineers dominate a program at the expense of biology, certainly. I can't comment as an insider on the extent to which this is a valid criticism within NASA, but you certainly hear it, and I notice that some of the people out at Houston that I have met, biologists, have resigned from the program because of the dominating position of the enginers in it.

I am sure there is talent, lots of talent, within the academic world that could easily be brought into collaborating with this space program; and, as a matter of fact, right now, as a result of cutbacks in budget, there seem to be a lot of biologists of various sorts that are looking for something to do, and this would give talent that could be utilized at very low cost.

This isn't true in my own field of ecology where there aren't enough of us to go around, but it seems to be true in a great many of the other fields.

As to making man the sole guinea pig, I would agree absolutely that this shouldn't be done; that we should try other types of organisms, plant, animals, micro-organisms, and so forth, that can answer

many questions that can't be answered with man because man is a very poor experimental animal for many reasons, and particularly when you get to things like genetic effects, he is an almost impossible experimental animal.

Mr. KARTH. You feel some experiments of this character that you have described on animals allows us an opportunity to extrapolate therefrom and apply those results to man?

Dr. COLE. Well, of course, this is what we always do. We start off looking at organisms that are better experimental material, and then this makes us suspicious that something we have discovered may apply also to man, and in the space program specifically it appears now that the radiation flux that causes genetic damage is affected in some way by this phenomenon of weightlessness. This has been apparent in fruit flies, in *Tribolium*, the flour bettles, and I believe in some other biological material that has been flown; and so it immediately raises a suspicion that perhaps this applies in man also. But it is impossible to be confident when you make these extrapolations.

I have been serving on Secretary Finch's Commission on Pesticides, and we have found very strikingly that often the effect of a pesticide we can't even extrapolate from a rat to a mouse, closely related as they are, and it is very dangerous to extrapolate from a monkey to a man.

But if you are testing a drug as a possible carcinogen, a cancer causing agent, you start off with something like a bacterium that is very easy to test and reasonable.

If it still looks suspicious, perhaps to try it on human cells in tissue culture. If it still raises suspicion, you move on perhaps to fruit flies. If it is still suspicious and you have to go into a mammal, usually a mouse, this becomes very expensive: and if it is still suspicious to the extent that you want to get closer to man and you have to run an experiment on monkeys, this is an extremely expensive process.

You can put millions of dollars into testing one chemical agent for carcinogenicity in monkeys to get confident results, and the same thing would apply here, and you are still not on perfectly sound ground in extrapolating from a lower primate to man.

Mr. KARTH. That is true. I would agree that from a dollar and cents standpoint, it is probably expensive to do this. However, I guess in the final analysis, it is considerably cheaper than to use man as the guinea pig. Particularly, I think this is true in space, because it costs so much more to put the man up there to begin with. These hearings are not being held for the purpose of determining whether or not we have any future manned space flights. It is to determine whether we can reasonably and sensibly have a biosatellite program to complement a manned space flight program in order to get answers to questions that we feel ought to be answered, or that a good part of the scientific community feels ought to be answered before and without using man as the guinea pig.

Dr. COLE. Certainly a phenomenon such as the interaction between the radiation flux and the weightlessness would not be turned up in man first. We are likely to have other surprises of that sort that will have to be turned up with other types of animals first, and it is a little bit hard to predict just what we may encounter in space or on the surface of Mars that will be of biological importance.

Mr. KARTH. Your point is that while you can't extrapolate some of these experimental results from monkeys, that if in fact there are some adverse effects, they raise warning flags.

Dr. COLE. Right.

Mr. KARTH. And because of these warning flags, then, whatever manned experiments we have, that they be conducted very carefully, I suppose, and very slowly and with a great deal of scientific study attached to it as the man proceeds to fly for longer periods of time. Is that accurately stating your position?

Dr. COLE. Yes, indeed. This loss of calcium from the bones of the astronauts and the loss of moisture from the body pool I believe, as far as I know, was first detected in man, and then in the biosatellite, the same phenomena showed up in the monkey that could have been used first to detect this thing, and this sort of reaction, obviously, if we are going to put man up on long space flights, 400 days going to Mars, or something like that, we have to be sure we know the answers to dealing with this sort of problem.

Mr. KARTH. What is the best way to get those answers before we embark upon some kind of a design and development program for long manned space flights?

Dr. COLE. In terms of manned space flight, I think the best way is to gradually lengthen the duration of the flights, see what adverse effect turns up, and try to solve them one by one, find out the answer to it.

Mr. KARTH. I don't think anyone disagrees with that. Everybody that has appeared before this committee certainly supports a 28-day and a 56-day flight; at least my recollection is they have supported it. The question is, whether or not the astronauts are really being, if I may use the expression, instrumented well enough and in a scientific way so that we do, in fact, know what is happening to the astronaut as he extends his stay in the weightless condition. The complaint is that really we haven't conducted enough experiments of this kind.

It has been kind of a trial and error thing. He comes back and we examine him and we find out something has happened to the calcium. He comes back and we try to find out whether or not something else happened; and in retrospect we find that the astronaut is really not instrumented well enough.

I am not talking about implantations. I am talking about other means that you know much more about than I do.

The complaint is that enough of this kind of work has not been done and is not now planned to be done in the programs that are on stage, so to speak, and about to be developed or are in the process of being developed.

You agree with that?

Dr. COLE. I believe so. I am not intimately enough connected with this to know just all the instrumentation that has been done, but a year ago, I would have taken it for granted that the urine of the astronauts was being analyzed almost continuously, and I was rather shocked to learn this wasn't the case. It seems to me this is something that should be done.

When you get to some of these things such as putting catheters right into the heart, this is surgically dangerous enough, so I think it was correct to use a monkey for this purpose first, and I am not sure—

again, I do not know enough about it—but I would be very reluctant to say we ought to do that to an astronaut at all while he is flying around up there.

Mr. KARTH. Since we have only conducted one such experiment, and that was in the minds of some, at least, rather inconclusive—certainly it was not a very lengthy one—do you think we ought to do more of that?

Dr. COLE. I would think so, yes, certainly before moving on to doing this sort of thing on man, and it is unfortunate it is so difficult to extrapolate because a little monkey like that has a much greater surface area relative to its mass than a man has, and so, as far as loss of moisture through the cutaneous evaporation, many things of this sort, it is very different from man. It does make it difficult to extrapolate.

Mr. KARTH. These experiments, I assume, could be conducted on man without any danger to his physical well-being, the last one you mentioned, evaporation.

Dr. COLE. I would think so.

Mr. KARTH. This has not been done. You would suggest these kinds of experiments be done on man in the 28- and 56-day flights: is that right?

Dr. COLE. Yes, and it seems to me, just offhand, you could put man in some sort of a suit such as skin divers wear and prevent this excessive evaporation or at least control it. Possibly I am wrong on that. I leave it to the physiologists to correct me, but I would suspect this is the case.

Mr. KARTH. Mr. Mosher.

Mr. MOSHER. No questions, Mr. Chairman.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. Thank you, Mr. Chairman.

Doctor, I am sorry I wasn't here earlier to hear your full testimony. Did you touch on the death of Bonny, the monkey, that was up 8 days in orbit?

Dr. COLE. No, I didn't.

Mr. DOWNING. Are you knowledgeable about that?

Dr. COLE. Well, I have read about it, and I understand that it was this loss of water and congestion of the large veins in the region of the heart and all that led to the deterioration and eventual death of the monkey.

I am told that some of the things that were suggested in the press, such as their losing temperature control within the vehicle and all, are incorrect.

Mr. DOWNING. Do you attribute this to the weightlessness of this animal?

Dr. COLE. This appears to be the case.

Again, now, I am speaking from second hand knowledge of this, but the pooling of blood that takes place in the extremities, in the feet, for example, is apparently very reduced under the weightless condition, and at the same time, there tends to be a congestion of the large veins within the body; so there is an increase in the venous blood pressure, and it is my understanding that this is what caused the deterioration of Bonny.

Mr. DOWNING. Well, we have had man up for a period of 14 days, and apparently none of this appeared in him.

Dr. COLE. On the very early space flights, physiologists out at Houston told me about this. They were quite alarmed at this moisture loss in a matter of just a few days, and also at the calcium loss, but Wayland Hull, who is a physiologist at NASA in Houston, when I visited there roughly a year ago, told me he thought he had this solved by having the astronauts exercise. He felt, at this time, this was the key to the whole thing, and they were going to have a regular program of exercise.

Now, of course, the poor monkey was absolutely restrained where it couldn't move around or get any form of exercise, and I don't know to what extent this may have been a contributing factor to its condition.

Mr. DOWNING. Thank you, Dr. Cole.

Thank you, Mr. Chairman.

Mr. KARTH. Mr. Pettis.

Mr. PETTIS. I am very interested, Mr. Chairman, in a couple of points that have been raised. One is this doubt about extrapolation. If it is true, as you say, that you cannot extrapolate information in closely related animals such as a mouse and a rat, is it possible we cannot extrapolate information that we get from the Russians, the Russian astronauts, and use that information in terms of our own astronauts?

Dr. COLE. No. Not as far as the biological facts of the thing go. I always have some little question about the accuracy of information we get from the Russians, but this may not apply in this area at all. To the extent they are really reporting their physiology results on Russians to us, I think we can extrapolate to Americans; yes.

Mr. PETTIS. Let me put it another way. Is it a scientific fact that there are significant biological differences, let's say, racially as between, say, a Japanese and a Frenchman?

Dr. COLE. I would be very surprised if there weren't differences, but I don't know what they are. There are, of course, known differences between the major racial groups, the caucasoids as against mongoloids and negroids. There are differences in susceptibility to disease and things of this sort, and because they are genetically different, which is responsible for the differences in their appearance, it would be very surprising if these genetic differences didn't also cause some small physiological differences, but this is an area in which we know, very, very little.

Mr. PETTIS. What I am really getting at is, are we missing something in our space program by not recognizing this to the extent we at least put three men in space who have at least somewhat identical possibilities in terms of reactions, physiologically, if there are physiological differences?

And that is my second question, does medicine generally recognize, for purposes of diagnosis and therapy, differences in national origins?

Dr. COLE. I don't believe so, to any extent; no, and it is very difficult, of course, to separate any of these things that might be genetically caused from things that are culturally caused. This is an area where anthropology is just beginning to take a serious look as far as I know.

Mr. PETTIS. For example, within species I know you couldn't take a jack rabbit from southern Arizona and put him up in the high

Rockies without him probably dying in a very short period of time; and visa versa, take the high Rocky Mountain hare and put him down in the desert of Arizona in 120° without something happening to to him—and yet they are actually very closely related.

So what I really am getting at is, isn't this something that we ought to maybe be checking into?

Dr. COLE. It would be exceedingly interesting, and I think the anthropologists would be excited about this, and I would love to know the comparitive physiology of an Eskimo and a Bushman, say, on a space flight. But I believe that the U.S. population is genetically similar enough to the Russian population so that I would think that extrapolations there would be relatively safe. They might be safe as extrapolating from a man from Texas as to a man from Illinois.

Mr. PETTIS. My last question is really the one I am serious about in our space program, and that is this business of periodicity. As I understand it, we don't really put the astronauts to the test in this as much as we might. Don't we accomodate to them in this period of sleep or wakefulness?

Dr. COLE. That is my understanding.

Mr. PETTIS. But on earth we have an abundant opportunity to study whether or not this has a significant physiological effect, do we not?

Dr. COLE. Yes, sir.

Mr. PETTIS. This business of what we commonly call jet lag from which we all suffer from time to time—what are the effects of this physiologically, this periodicity?

Dr. COLE. Back when I was a graduate student in the early 1940's, I had some association at the University of Chicago with Nathaniel Klietman, a physiologist, who can be said to be the pioneer in studying these sorts of things. He was going around taking the temperatures hourly of people in different sorts of occupations. He found that musicians, for example, that were working all night, had the daily temperature cycle that was exactly the mirror image of those people who are working during the day and sleeping during the night.

He was taking volunteers down into Mammoth Cave to get away from the daylight rhythm and trying to adapt them to a day length other than 24 hours, trying to put them on a 30-hour day, and things of this sort.

I think the conclusion can be summarized by saying that some people can make the adjustment and others can't. That is my recollection.

Of course, there still are periodicities on earth, even in a place like Mammoth Cave. You get away from the light-dark cycle. You get away from the daily temperature cycle, but it is my understanding there are measurable changes in barometric pressure in the trace gases in the atmosphere, in the earth's magnetic field, in the flux of cosmic radiation, and so forth, that many of the things we don't know people can detect, but that might in some way be detected and tied up with regulating these periodicities. Getting clear away from the earth would give a possibility of separating these things.

Mr. PETTIS. Thank you, Mr. Chairman.

Mr. KARTH. Mr. Symington.

Mr. SYMINGTON. Thank you, Mr. Chairman.

Mr. Pettis' questions interest me, too, and also your earlier mention of the effect on men of water loss in space flight. I remember

hearing last year about an experiment that I think was funded by the U.S. Government in which an attempt was made to learn why the aborigines of Australia indeed do not sweat as much as other people.

This was brought up in a somewhat political context to question the use of American funds. The defense of it was that young men in Vietnam tended to lose a lot of moisture and they were wondering if there was some way to transfer artificially the physiological ability to withstand high heat without losing water.

Are you familiar with that difference?

Dr. COLE. No, I wasn't. I know a little bit about this adjusting to high temperature. I remember clear back when they were building Hoover Dam or Boulder Dam, they had a very high sickness rate among the men, and it was at that time that they first discovered this excessive salt loss, and as this has been studied, why, it appears when you are exposed to the desert environment for some time like this, that at first you lose a lot of salt with the perspiration. Then you lose some more and do not lose so much in later periods.

I am sure that physiologists—I believe it was Scholander that was mixed up with this study of the abordigines. I am sure they are looking in much more detail for things I wouldn't even be aware of which might be involved in these adjustments.

Mr. SYMINGTON. You mentioned at least one scientist considered the exercise as the corrective activity. Do you mean to say that exercise actually retains moisture?

Dr. COLE. This was, I believe, in connection with the calcium.

Mr. SYMINGTON. It was ambiguous.

Finally, given your apprehensions and concerns, before we embark on a 2-year flight well beyond the opportunity to retrieve men, would you like to see, for example, a space station in retrievable orbit, possibly visitable by astronauts from time to time, containing both men and animals for a period of time commensurate with a 2-year period?

Dr. COLE. I think this would be highly desirable if we could have a shuttle system so that when danger signs arise you could quickly get the men back here, and a lot of things could be done from such a statino. You could even put a telescope on it, I presume, and learn a lot of things that are blocked to us at present by the atmosphere.

Mr. SYMINGTON. Would you believe that the configuration of the ultimate space ship to Mars, as well as its supportive systems internally and all the aspects of it, the design of all those things, could well await information that could be gained by such an experiment as we have discussed?

Dr. COLE. I really don't know anything about the configuration, but I would think that such studies as learning how to recycle the water, to recycle the oxygen, possibly looking into life-support systems to the extent even of being able to produce food on a space flight, these are going to take a lot of study, and I think we should get on with those very quickly.

Many problems of this sort are going to arise. We are going to find on these longer flights, I suspect, that the traces of chemicals we are scarcely thinking about now, ammonia and methane and things like that that are given off by the human body, are going to require special attention on a prolonged flight, and I think we should immediately try to uncover and learn how to deal with these things.

Mr. SYMINGTON. One final question. How did you precisely inform yourself about the biosatellite III and Bonnie, the monkey's experience?

Dr. COLE. Simply by reading materials that the AIBS staff gathered and turned over to me.

Mr. SYMINGTON. Did you have an opportunity to consult with any of the scientists that worked on that?

Dr. COLE. I have talked with Dr. Reynolds on the subject, yes.

Mr. SYMINGTON. Do you think you could have gotten just as much out of the press conference as you did from reading the materials?

Dr. COLE. I don't know that. I can't answer.

Mr. SYMINGTON. Have you ever been to a press conference after one of these flights?

Dr. COLE. No, I never have.

Mr. SYMINGTON. Would you expect to learn as much?

Dr. COLE. Not really. I think the things the press is interested in are not always the scientifically most significant.

Mr. SYMINGTON. Thank you very much.

Thank you, Mr. Chairman.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. Can you correlate, in any way, a human being in a sleeping condition and his condition in space?

In other words, if you were confined to bed for a couple of weeks, wouldn't you have a similar loss of calcium, your blood would be recirculated in the middle part of your body, and you would have a little dizziness if you got up quickly and things like that?

Dr. COLE. I don't know about this cardiac condition. I don't believe I have ever heard that there was an increase in veneous blood pressure within the body under the condition of bed rest. The calcium loss, the degeneration of muscle tone, of course, is very similar under those conditions to what we have seen in space.

Mr. KARTH. I think one of the concerns of this committee and of the Congress, insofar as it relates to manned flight, Doctor, is that a manned flight program not just be a program to see whether or not we can keep a man alive in space or whether or not, for that matter, he is a useful performer in space, which is in itself some kind of a laudable experiment we ought to conduct; but, more importantly, to gain information, important medical knowledge, and apply that medical benefit of all mankind.

Now, that is one of the really important areas, I think, of manned space flight or any outer space program, that is of particular concern to this committee.

What can we do to capitalize on this great investment, this interesting scientific investment? What can we do to capitalize it? How can we apply those experiments to the benefit of mankind here on earth? That is really one of the salient questions, if not the salient question, I think this committee is interested in. So to do that, we have got to do more than just fly man and then, if you will, in retrospect, extrapolate this to what really happened to him, how important it was, what he can and can't do, how he can or can't develop himself in space so that he can adjust to the rigors of outer space.

Do you agree with that as one, if not the primary objective of manned space flight?

Dr. COLE. I am sure the instrumentation that is coming out and has to be developed for the purposes of manned space flight, I believe it already has turned out to have some significant benefits in medicine.

I would rather a physiologist talk about what we might learn physiologically there that would be applied to medicine on earth, but we have already mentioned the two really distinctive things that a man is exposed to that we can't simulate on earth. These are weightlessness and the absence of these earthly periodicities. We have known for a long time simply from statistical information that there is a daily rhythm in the death rates. More people are dying at one time of the day than at another. There is a rhythm in the birth rates.

What happens if you get people away from these rhythms? I suppose it is conceivable this might be the proper therapy for some condition. I wouldn't want to guess what it might be. The same with weightlessness. It is conceivable to me that this makes enough of a physiological difference that it might take the strain of functions off some organ that hasn't been detected yet; that perhaps this would be therapy for some of sort of condition.

These are so completely different from anything we have had experience with, that I think we just have to look very carefully at what is happening to man in space, and we can expect some surprises to turn up.

Mr. KARTH. Well, the question really isn't, I guess, how much we have already benefited from manned space flight in a medical sense, but how much we are able to benefit from future manned space flight if we go about it properly—if we really tune our efforts to trying to get answers to these questions that have harrassed us all of these years in the field of medicine, and whether or not manned space flight can provide answers to some of these questions, the application of which will enhance life and the well-being of mankind here on earth.

Don't you think that is a very worthy objective for this committee to look into?

Dr. COLE. Yes, indeed. I think the benefits could be tremendous. You could conceivably learn more about the physiological functioning of a man over, say, a 15-day period in space. You could monitor everything to the extent that you would know more about his physiology during this period than you would almost ever know about a person here on earth, simply because we haven't monitored him so carefully.

Mr. KARTH. You said something about your interest in a manned Mars flight. I think that most Americans would like some day probably for man to explore the planets. At least I would. But there are many of us who feel that so many questions must be answered prior to our designing some kind of a spacecraft and developing the attendant paraphernalia hardware to get there that we have got to do a good deal of laboratory work, a good deal of homework, a good deal of biological scientific exploration on manned space flight before we even begin to think aggressively about designing and developing a manned Mars flight.

Would you agree with that?

Dr. COLE. Yes, I am sure we are a long way away from being able to send a man off on a 400-day flight in space.

Mr. KARTH. What do you think about the Viking program? Are you familiar with the unmanned Mars soft landing program that is now in development?

Dr. COLE. Slightly. I have heard of it. Well, the thing I was afraid of, contaminating Mars, has probably already happened, if it is going to be contaminated.

I was against sending anything to Mars and to Venus. I didn't realize what an inhospitable place Venus was at the time.

Mr. KARTH. It is probably a good thing we took a look before we sent man up there.

Dr. COLE. Yes, indeed. A great deal of information can be gathered by unmanned equipment; but as far as our basic biological knowledge goes, life could exist in some form so completely different from anything that we have had any experience with or even conceive of, that I don't think we would know how to construct a gadget to detect it. There is even a theoretical possibility some biochemists have speculated about——

Mr. KARTH. You mean whether we send a man up or whether we send an instrument up there?

Dr. COLE. I think a man would be able to recognize these things, but I am not sure we would design an instrument to recognize it. Suppose there is a form of life like an amoeba, except instead of being based on proteins it is based on polysaccharides, a huge carbohydrate molecule. It could be conceivable.

Mr. KARTH. He would have to bring some back and we would have to send it through our laboratories in order to determine whether there was this condition.

Dr. COLE. With an unmanned system, we would have to bring samples back; yes.

Mr. KARTH. How could a man determine it by going there if he didn't know what it was?

Dr. COLE. If the thing is moving around like an amoeba, I think he would recognize it is a living system. He sees it eating.

Mr. KARTH. Don't you think we could do this with an unmanned system by using cameras?

Dr. COLE. Maybe it is growing like a plant instead of crawling like an amoeba.

Mr. KARTH. We could still see it in the camera.

Dr. COLE. This is conceivable.

Mr. KARTH. If it is self-evident, we will get the information with the camera just as well as we do through the eyes of a man; but as an ecologist, you may disagree with that.

Dr. COLE. We don't know what we want to program the instrument to look for. I think a man is considerably more versatile this way.

Mr. KARTH. It might be well if some of these things are crawling around that we would not want to send man to begin with.

Dr. COLE. This is possible. There is certainly going to be some risk involved in either sending a man up there or bringing samples of the material back. I wasn't concerned really about the moon. I expected the moon to be completely uninteresting biologically, but I am not so sure about Mars. In fact, Mars looks like our single best hope in the whole solar system for finding things are are biologically interesting.

Mr. KARTH. Many intelligent people, after taking a look at the Mariner VI and VII pictures, and comparing those to the pictures we have received from the lunar surface, have now concluded that

Mars is pretty much of a desolate place like the moon, although there isn't any evidence prior to having the pictures. There are some suspicions that are probably comparable to those you hold.

Dr. COLE. It looks desolate, all right, but I think there are organisms from earth that could survive it, from what I have seen in the literature.

Mr. KARTH. Why do you think you say it is already contaminated?

Dr. COLE. We have shot. I don't remember whether it is what the Russians or we that sent the first thing to land on Mars. This is what I was opposed to, and, of course——

Mr. KARTH. I don't know of anybody that has, Doctor. You may have information I don't have.

Dr. COLE. I thought they had.

Mr. KARTH. Nobody claims to have done this.

Mr. DOWNING. The Russians impacted Venus.

Dr. COLE. They did on Venus, yes. I perhaps am wrong on this. I thought something had been landed on Mars.

Mr. KARTH. I think the Viking program will be the first, at least for the United States, whether or not it will be first for the world. I think that is the first effort that the United States will make to land and do some scientific experimental and scientific work on the Martian surface.

Dr. COLE. I guess I am not that up to date on your program.

Mr. KARTH. Are there any further questions?

(No response.)

Mr. KARTH. If not, thank you very much, Dr. Cole.

And now, Professor Carlson, who is chairman of the Division of Medical Sciences, School of Medicine, University of California at Davis and member of Space Science Board, National Academy of Sciences.

Thank you very much for being with us, and proceed, sir.

STATEMENT OF PROF. LOREN D. CARLSON, CHAIRMAN OF THE DIVISION OF MEDICAL SCIENCES, SCHOOL OF MEDICINE, UNIVERSITY OF CALIFORNIA AT DAVIS AND MEMBER OF THE SPACE SCIENCE BOARD OF THE NATIONAL ACADEMY OF SCIENCES

Dr. CARLSON. I am glad to be here, Mr. Chairman.

First of all, I am a physiologist by training and I probably have some biases since I have been involved in aerospace physiology since the beginning of my professional career although I have been involved in teaching at the university as well.

I would like to discuss and support a biosatellite project within the NASA program.

I have given you the text of my statement and so I would like just to go through it briefly and comment about it.

I believe that the post-Apollo program as outlined to the President by the space task group report clearly indicates the need for biological and medical studies in any of the alternative goals in directions for the future. I am hopeful that the President and Congress will support the rational and ambitious program objectives set by the space task group—that is to say, the long-range option or goal of manned planetary exploration.

The biosatellite project supports two broad programs in NASA—one, a new area of biological research related to the new environment of space and, the second, the strong supportive role in qualifying man for long-duration space flight. It is of intrinsic interest to find out how organisms react to an entirely new feature of the environment. It is also imperative to have the capability to investigate specific physiological functions demonstrated to be of interest in manned flights which can be more thoroughly documented in animal experimentation. At present, there are questions of hemodynamics, body fluid distribution, neurological problems of sleep and wakefulness, and circadian rhythms. As space flights are prolonged in time, we must be prepared to react to these and other questions.

I wish to emphasize a value of the biosatellite program that is often lost in the attention to the costs, schedules, and technology involved. Scientifically, the biosatellite program has many of the aspects of an iceberg. The visible and financially apparent space flight is supported by an extensive ground-based effort which provides the scientific basis to make the flight experiment meaningful. The validity and reliability of biological data acquired from single or duplicated experiments is necessitating a strong ground-based programmatic approach to many basic biological problems. The personnel involved in these studies form a huge national asset of value in training as well as support in other key areas of national interest, such as environmental sciences and health sciences. The science in space flight is necessary and costly but it should be considered as part of the total science and technology which support the program.

I think it is important to assess the returns from biosatellite flights completed to this date and to recognize that follow-on biosatellite projects will be considered in relation to the projected manned program. Biosatellite I demonstrated a well-known engineering fact—that sometimes well-proven systems fail. Biosatellite II was successfully completed and the results documented. Results have been reported in great detail in an issue of Bioscience in 1968. Biosatellite II scientific findings have been summarized by K. Thimann. He presents a number of scientific conclusions from these experiments. He indicates the orbiting does not bring about changes that have not been indicated by gravity balancing experiments on the ground. He did report that radiation and flight conditions do interact. However, Thimann and the Academy reported that the data offer no good reason to plan for a repetition of the flight of biosatellite II.

There was an intermediate—21 day—biosatellite flight planned. This has been canceled. This flight contained experiments for which the need has been affirmed by a 1969 summer study chaired by Dr. Thimann on the Santa Cruz campus. The recent Biosatellite III experiment was terminated early, yet will yield considerable information. The principal investigators for Biosatellite III report their preliminary findings in Science, and I shall not say more about their findings.

It is important to remember that the first manned flights in Mercury were preceded by flights of subhuman primates which established the performance of the life support system.

I have mentioned the summer study chaired by Dr. Thimann during this past summer. The Space Science Board and many in-house

committees in NASA have documented the biological and medical experiments for space flights. A few of these are not in the Apollo applications program. Many more are detailed in Space Science Board reports listed there of which copies, I am sure, would be available to the committee. I might point out these reports have been very carefully reviewed by NASA personnel. They have been discussed by the committees who prepared them with NASA personnel, and at the present time there are a number of mechanisms whereby the progress in achieving some of these activities are reviewed periodically with the proper people and committees in the Space Science Board. Each of the offices in NASA have been very receptive to the advice which these groups gave them.

I would like to indicate in a categorical way the range of interests in the biological, biotechnology, and medical areas.

In the mammalian system, the principal interest is the cardiovascular system. It was hypothetically or theoretically suggested and now has been shown by actual measurement this system would show alterations in weightlessness, a phenomenon some have called "deconditioning" but which I prefer to call the "space adapted state." The recent primate experiment demonstrated some of these changes.

There are other mammalian systems similarly involved. We mentioned the structural system of bone and we also should mention muscle. Many of the endocrine systems would be involved. Another important field of interest in space flight is nutrition and a third is the effect of isolation and small group dynamics. Each of these, I might say, has been studied by small groups within the Academy's Space Science Board.

The proper specification for a life support system requires a large biotechnological effort. These range from the simple (but enormously difficult) tasks of housekeeping and sanitation to the possible requirement of an artificial gravity—and at what gravity level—and for what time periods.

The biosatellite project connotes animal and plant experiments. These require justification on the basis that the studies are on a basic and general physiological process common in all of biology, such as dimension changes or cellular processes, or that the studies are on systems that are analogous to the human for application purposes.

Much of what is of use today in medical science has been brought to application in this manner. Organ transplants are a good example. However, with respect to manned space flight, animal experiments must be chosen with great care and their interpretation viewed with caution.

There are important "scaling factors" relating physiological disturbances in time from one animal to another. The life span, or aging, is a good example. Secondly, there is a scaling factor of size. Some physiological functions appear to be independent of body size. The time of recovery from a water load is the same in the rat and in man according to Dr. Adolph. An animal's response to exercise is proportional to size but the rate of response is not.

In other physiological systems, the rate of response may be size dependent. Recovery of normal body composition after exposure to more than 1 g. seems to have this characteristic. The albumen turnover (an important osmoregulation component in blood) is related to the body weight to the .66 power. It is a power function of weight.

Thus, one might use animal experiments to establish or to predict the time course of responses and the scaling factors from animal to man have to be established.

An ad hoc bioastronautics panel of the space technology panel of PSAC reported in 1963 that their knowledge of physiological time bases for adaptive processes in man indicate that the changes occur in appreciably less than 90 days. In an animal smaller than man, these processes might take less time. This would make an opportunity to study it.

It is a matter of fact, as has been mentioned, that the Russian space program has included a number of biological experiments—both at the cellular and mammalian levels. I think these have been very well documented in a staff report for the Committee on Aeronautical and Space Sciences.

In support of Biosatellite II and Biosatellite III, there were a large group of scientists working on the basic biology and a large group of engineers designing a suitable capsule and life support system. I wish to emphasize again that without a follow-on biosatellite program, the United States will lose not only the capability to study biological problems in space but that large asset of trained personnel in science and engineering necessary to support it. Without biosatellite, these people will turn to other tasks.

Thank you.

Mr. KARTH. Thank you very much, Professor.

Mr. Pettis.

Mr. PETTIS. I would like to go back over one point I raised before and ask the Doctor if he feels that this ability to extrapolate is easily or not easily done. May I proceed by saying we have had testimony this week that would indicate there is quite a difference of opinion in the scientific community on this point, I would like to get your views about it—whether it is from a monkey to a man or between human beings.

Dr. CARLSON. Let me deal first of all with respect to going from one animal to another or from a subhuman primate to the human. I think it is quite possible to study the general characteristics of any system, but as I indicated in the text of my report, one chooses these systems so they can be made analogous. For example, much of what we know about cardiovascular dynamics has been learned from experiments on dogs.

A great deal of what we know about neurophysiological activity has been deduced from studies in cats and in the monkey. Now, what is required is the right set of studies which indicate that you are on firm ground in making the transfer to man and so you do a series of experiments which in a sense duplicate certain aspects of the experiment you have done in the animal to see whether the same things hold. This has been carried out again and again, and so, that I guess the point I would like to make is that in the extrapolation one wishes to make, any carryover you wish to have between animal experiments and man should be done in a carefully controlled way so you do make some tests with man himself to determine whether your predictions are right.

Mr. PETTIS. Not to put words in your mouth, but you are saying, then, that there are valuable things we can learn from animal experiments in this space program?

Dr. CARLSON. Indeed.

Mr. PETTIS. You would not agree with the idea that precursor experiments are unnecessary to manned space flights, as far as using the data is concerned?

Dr. CARLSON. I think I would like to put that another way.

I don't think that the animal experiments are essentially precursors, although they are desirable precursors. There is an alternative path which is the incremental approach in studies on man.

Mr. PETTIS. Thank you, Mr. Chairman.

Mr. KARTH. Mr. Downing.

Mr. DOWNING. Professor Carlson, or Dr. Cole, either, do you know of any life function that is independent on gravity?

Dr. CARLSON. I am having difficulty interpreting the question. A number of life functions, function in the way they do because of gravity.

Mr. DOWNING. If you take it away would the function continue?

Dr. CARLSON. Insofar as we know with respect to mammalian systems the function does continue, yes.

Mr. DOWNING. What life function would you say is dependent on gravity?

Dr. CARLSON. I would say there are a number of life functions in which the characteristics are dependent on gravity. Certainly the circulatory system is one of these. The adjustment from going from a horizontal to a vertical position in the circulatory system is a gravity dependent function, where there is no gravity that adjustment would not be necessary. There are differences in difusion and perfusion in the lung which appear to be gravity dependent. Were there no gravity this difference would not exist.

Mr. DOWNING. When you take away gravity and put the human body in the weightless state, the function still continues?

Dr. CARLSON. That is correct. We essentially take away that particular forcing function on the system.

What I am saying, Mr. Downing, is that these systems have built into them response mechanisms for reacting to gravity.

Mr. DOWNING. It seems to me the good Lord knew what he was doing when he made man. He made him almost adaptable to any environment. Certainly it did not depend on gravity. Is there any evidence to show that the aging process changes in any way in a weightless state?

Dr. CARLSON. Not to my knowledge.

Mr. DOWNING. Thank you.

Thank you, Mr. Chairman.

Mr. KARTH. Mr. Symington.

Mr. SYMINGTON. Professor Carlson, would you think we have learned more from the Russian space program in biomedical information than from our own?

Dr. CARLSON. I think not. They have more extensive experience, perhaps, with animal experimentation, and even, perhaps, with plant experimentation.

We have, of course, more experience with man and with more men than they have. I think that perhaps I am more familiar not only with the results from our biosatellite and from our manner program, and also with what I really wish to emphasize again, the very broad basic program that goes on to make this all meaningful underneath.

It is going on at the universities and at NASA Laboratories to say we have considerable more information about the physiology of man from that total program, American program, than we do from the Russian program.

Mr. SYMINGTON. And the corrollary, they have learned more from our program than they have from their own.

Dr. CARLSON. I shouldn't answer for them, but it is possible.

Mr. SYMINGTON. If we have been equally free and candid with our information.

Dr. CARLSON. I think we have, yes.

Mr. SYMINGTON. We had testimony last week—I think it was Dr. Adey, if my memory serves—that because of some instrumentation such as for eye movements, I think was one of his specifics, that are indicia of nausea, the Russians had experimented with man and we had not, and they had some useful information there, nausea being an experience of our astronauts, but perhaps not followed in that particular fashion. It was his view that overall we had learned more, biosatellites aside, we had gained more biomedical information from their manned program than from our own.

Dr. CARLSON. The specific points he gives is an experiment they have done and we have not done exactly as they have. However, Dr. Ashton Graybiel is certainly working on experiments of that type which will be included in the Apollo follow-on program. Dr. Graybiel is with the Naval Aerospace Medical Institute at Pensacola, Fla.

Mr. SYMINGTON. In your studies of the Biosatellite III—the monkey's experience—how long did you spend with that project in order to familiarize yourself with what happened? Any time?

Dr. CARLSON. The information I have is what actually is published in Science magazine.

Mr. SYMINGTON. I have not seen this publication. Is it a lengthy treatise with careful footnotes and all kinds of scientific data?

Dr. CARLSON. No, this is a preliminary report without the major part of the data.

Mr. SYMINGTON. If you were going to have to decide to send men to Mars, or on any other mission of that duration, would you want to authorize such a mission without an opportunity to examine men in space for nearly that length of time in a more retrievable orbit?

Dr. CARLSON. No, sir; I would not. Actually that was the sense of that small ad hoc committee report from the Space Science and Technology Panel that I referenced in my presentation. I happen to be Chairman of that panel, that ad hoc Panel, and we, I think, spelled out very clearly that one approach in the study of man was an incremental approach so he would be retrievable, so you would have the measurements which a competent group of scientists felt would give the key physiological responses you wanted to be studying.

I think in respect to what was said earlier about settling on the final technology for a Mars mission, that ad hoc Panel also felt that these experiences in earth orbit would be necessary before you finally settled on what the configuration of the Mars craft would have to be and you

could work with a certain amount of responsibility there, and I think with respect to what the supportive measures should be.

I think we ought to make it clear while man does adapt very well to many kinds of environment, the engineers do a remarkable job of supplying the environmental support for him. Space travel would be completely impossible without the space cabin and its environmental control system. We can do this with respect to other systems that need support as well.

Mr. SYMINGTON. Do you have any judgment at the moment as to after what incremental increase in duration, when the great leap could safely be made, when you would be fully satisfied that man had been tested in space long enough to make a 400-day trip?

Dr. CARLSON. At the time we did this study, I felt, and I think I would still stand with this, that somewhere between 90 and 120 days of experience would allow me to settle on the requirements that the engineers would need for designing the station. With that I make the assumption that any hardware which would be used for a Mars flight would also be tested out in earth orbit and so I would have a second attempt to be sure that my design was functioning.

Mr. SYMINGTON. Is it your feeling that the presence of a similar experimentation with animals would be helpful as well?

Dr. CARLSON. Yes, I have always found that to be the case and I can only use my own work in the laboratories for an example. I happen to be interested in human physiology, but we often set up parallel experiments in animals. At one time in my career I was interested in adaption to living in a cold environment and we came up with changes in the peripheral circulation and also metabolism in man which we had to check out in animals, and I spent 15, 20 years of my life following up on those leads which, I think, were of some significance.

Mr. SYMINGTON. Thank you very much.

Mr. KARTH. Mr. Koch.

Mr. KOCH. Professor Carlson, you really have established this for me in my own mind by putting labels on the two different points of view that have been presented to this committee in the several days of testimony we have had. One is this use of the incremental stage with man as the guinea pig, and the other is the use of the subhuman primate in the experimental stage preliminary to that.

What seems to me to be the most distressing aspect is that those who were engaged in furthering the incremental stage—and notice I have reference to the testimony of General Humphreys—there seemed to be a certain rigidity because of the language he employed. I quote him correctly, I believe.

He said that these bioscientific experiments—alluding primarily to the monkey experiment for a moment—were laudable (that was his word) and scientifically interesting. Those were his words. But that they weren't vital. He in a sense said that what happened to one monkey really was not very important with respect to the program to put man in space. I don't think I misquote him on that, although I am paraphrasing him.

What was even more disturbing was when we pressed him to ascertain how he came to these conclusions, and did he have these conclusions before he received the report with respect to Bonny, he said he had an opinion and it was reinforced as a result of a press conference and a preliminary briefing prior to the press conference.

Now, I bring this to your attention because it was disturbing that those in charge of a very important program, who had a point of view favoring the incremental stage with man, seemed to resist the experimental stage.

Do you have a comment on that? Is there something wrong with the program where the two are not meshed more closely?

Dr. CARLSON. Well, I think that part of the reason that the two programs don't appear to be meshed closely at the moment may be with respect to the difference in objectives that were part of the initial program. I must say I participated in a number of discussions which were involved in attempting to achieve the goal of man on the moon by 1969. These are essentially technological achievements. They meant essentially taking some reasonable guesses if you were going to achieve the goal.

At the same time I believe that the Office of Space Science and Applications group under Dr. Reynolds had proposed a very reasonable set of experiments to support this, and they were certainly moving along. They were delayed by some budget problems perhaps, but they were moving along.

I think perhaps that you may be overstating the case slightly. Had there been any specific difficulties at any time in the 3-, 5-, 7-, 14-day sequence, I think we would have relied immediately on animal experiments in order to ferret out the difficulty.

At the present time I think that the investigators in Biosatellite III would agree with me that they had raised a considerable number of quesions about the primate experiment which need to be answered because of the disparity in the outcome of the experiment, the lack of fulfilling the 30-day time period, which in itself then would have been a lead in terms of the manned experience.

Mr. KOCH. Just pursuing that, it is clear that there are unanswered questions coming out of that experiment with Bonny. If I understand it correctly, all of the data has not yet been analyzed and we were told that the final report would probably be available in January of next year.

So, one of the questions raised by members of the committee was, would it not make sense before continuing with large investments of money in the 28-day program for man, that we have the answers as best they can be ascertained and await this January report preliminary to making these huge investments? What would your point of view be with respect to that?

Dr. CARLSON. I believe that the present language with respect to the 28-day experiment is that the formulation of the biomedical experiments could well be adjusted to take into account what we learned between now and January, and it would seem to me then that I wouldn't propose to stop this planning or the investment because there are many other reasons for the investment.

I would like to make a comment which I think is apropos to this, but also with respect to your referring to the current PSAC report. I think that Apollo is an interesting stage in our space program. It is at an interesting stage in its development. We have proven the technology in the sense that it was suggested as a goal. It now really seems to me that much of the justification for our space program is scientific and so it should be paced by the scientific goals, and I think the Space Science Board has said this in its report several times.

Mr. KOCH. Wouldn't it make sense to have an experiment involving a subhuman primate, another Bonny, and have that animal come back alive in a 14-day tour, that is, to fulfill the 14-day tour before we venture on a 28-day tour for men?

Dr. CARLSON. I think it would be a help, yes. I think it would be a help to do a second experiment with the subhuman primate in order to answer the questions that have been raised by this present flight.

I believe, however, that the programing in terms of kind of measurements that will be made on man and the opportunity, of course, to retrieve or to support him in the case something does go wrong is such that that experiment I would consider could go on in parallel.

Mr. KOCH. If we heard testimony correctly, it seemed to be obvious there are experiments with respect to measuring what occurs to an animal that couldn't possibly be made on man—such as the mechanisms implanted in the heart of the monkey. They can't implant those mechanisms in man or one shouldn't implant them in man because they are going to fight them.

Since we recognize that, are there any plans to have another monkey in space for a 14-day tour?

Dr. CARLSON. To my knowledge—and this could be corrected by people there—at the present time the biosatellite program is terminated. There is not another.

Mr. KOCH. If you were to be in a position to make a decision on that matter and you are, in effect, because you are advising us, would you urge that we continue that program and at the very least have one or more experiments involving tours of 14 days or maybe 28 days for subhuman primates?

Dr. CARLSON. I would. As I said in the opening second or third paragraph of my presentation to you, I think that there are two reasons for it: one, with respect to the science involved and, second, to have a supporting set of experiments for the manned program.

Mr. KOCH. Then would it be correct to say you think such a program is more than laudable?

Dr. CARLSON. I think I have semantic difficulties with laudable.

Mr. KOCH. Would you say it is more than merely scientifically interesting?

Dr. CARLSON. I would say it is scientifically worthwhile.

Mr. KOCH. Would you say it would make a great, meaningful contribution with respect to assuring the safety of our men when we send them up for a 28-day mission?

Dr. CARLSON. It has that possibility.

Mr. KOCH. In your judgment would it make that contribution, that is to say, not to be involved in semantics, would your feelings be more than it is just a possibility?

Don't you think it would in all probability have a meaningful contribution of a substantial nature?

Dr. CARLSON. I agree. I happened to be involved when the biosatellite program was initiated in the committees that discussed it. I thought it was a worthwhile program then; I think it still has that same potential.

Mr. KOCH. Would you believe it is a gross error and misjudgment to cancel it on our part?

Dr. CARLSON. That is putting it pretty strongly.

Mr. KOCH. I am trying to put it that way.

Dr. CARLSON. I was sorry it was canceled.

Mr. KARTH. Pursuing one of the questions that Mr. Koch asked, Professor—and I can appreciate why you, like the rest of us, have so much trouble with the word "laudable"—but you used the word "imperative." I assume you had complete understanding of how you used it and why you used it this way.

You said on page 1 of your testimony—

It is imperative to have the capability to investigate specific physiological functions demonstrated to be of interest in manned flights which can be more thoroughly documented in animal experiments.

Do you want to amplify upon that statement, in answer to Mr. Koch's questions?

Dr. CARLSON. I guess the semantics of the question, gentlemen, is in that I say it is imperative to have the capability to investigate.

Mr. KARTH. We don't have the capability now.

Dr. CARLSON. That is right. We don't. If it were necessary to make investigations in animal experiments at the present time, even though they were called to your attention by continuing the manned flight, we would not have the capability.

Mr. KARTH. In the next sentence——

Dr. CARLSON. Could I expound on that a little bit because that capability is more than just a capsule in which a primate can fly. It is a fantastic group of people who are working in laboratory experiments to provide the broad base of information you need to give significance to the data you get from that single or double flight.

Mr. KARTH. Today we don't have that either, do we? We don't have it put together to accomplish the objective.

Dr. CARLSON. It is essentially falling apart.

Mr. KARTH. You go on to say in the next sentence, "At present, there are questions of hemodynamics, body fluid distribution, neurological problems of sleep and wakefulness, and circadian rhythms."

Are these the experiments that you feel must be conducted on man in future manned flight which to date have not been conducted?

Dr. CARLSON. We have some information on some of these in manned flight, but I would say most certainly I would agree with you that the experiments and the measurements should be made in manned flight and they can be made, I might say.

Mr. KARTH. They can be made?

Dr. CARLSON. Yes.

Mr. KARTH. We have had some discussion over the course of these hearings as to what we really have accomplished in terms of biomedical experiments on the astronauts in the some 5,000 hours of flight we have racked up, and what additional experiments we ought to really do.

I would like to have you provide for the record the experiments that to your knowledge we have in fact conducted on man during these 5,000 hours of space flight, the importance or the irrelevance of them, and those experiments that you think we must conduct in future manned space flight programs.

Could you do that for the record; not at this moment, but for the record?

Dr. CARLSON. I presume you are giving me a carry-home assignment.

38-758—70——16

Mr. KARTH. It would be helpful to the committee if you would do that.

Dr. CARLSON. I will, yes.

(The extension of remarks prepared by Dr. Carlson under date of December 9, 1969, follow:)

It is first necessary to indicate that I am defining experiment in the broadest sense, as a test or trial with respect to my discussion of the information gathered to this date in manned space flight. The more specific definition of an experiment—an act or operation carried out under conditions determined by the experimenter in order to discover some unknown principle or effect, or to test, establish or illustrate some suggested or known truth—applies in part to these experiments, but it is the more rigorous definition which scientists would wish to apply to those experiments considered necessary in *future* space flights.

Those tests to be discussed have been described in detail in NASA reports on the medical aspects of the Mercury flights and the medical aspects of the Gemini flights. Material concerning the bioastronautic aspects of Apollo medical operations was obtained mainly from an article with that title presented by James W. Humphreys, Major General, USAF, and Charles A. Berry, M.D., at the 20th International Astronautical Congress held in Argentina, October 5–12, 1969. The writer has been the author of two papers: The first, "The necessity of biological experimentation in space," published in Volume 17 of *Advances in the Astronautical Sciences*, 1964 and the second article, "Has man qualified for long duration space flights?" published in *Astronautics and Aeronautics* in May 1967.

Mercury and Gemini flights were preparatory for the Apollo flights. On the Mercury flights—from a trajectory flight to three days of orbit—the biomedical data included voice communication, and electrocardiogram and respiratory frequency transmitted to the ground. The blood pressure was measured periodically. The spacecraft carried additional monitors for its pressure, carbon dioxide tension, and the incident ionizing radiation.

In the Mercury flights, some attempts were made to assess performance by following the manner in which the manual control of the aircraft followed the simulations that had been done earlier on the ground. The medical experiments conducted on flight crews are shown in Table I, reproduced on the following page.

The Russians have carried similar experiments in their flights and have added some prescribed performance tests. In addition to the electrocardiogram, they have used a device known as a kinetocardiogram, and they have followed the eye movements of the astronauts.

Following flight, in addition to the standard clinical examination, a post-exercise tilt test was used to determine whether there were changes in the cardiovascular system and pre- and post-flight tests were devised in the Gemini 7 flight to determine specifically whether there were changes in calcium balance and nitrogen balance, as well as the usual tests of blood volume change. The electroencephalograph data during flight have revealed no aberrant changes. Heart rate during extravehicular activity has reached rather high levels and this is evidence of the difficulty that is faced in making maneuvers in a pressure suit in a weightless environment. The electroencephalographic data has provided information on alerted behavior, drowsy episodes and depth of sleep. An analysis of this data has led Adey and his colleagues to point out that some differences in the 4 to 7 cycle per second band in the waking state in flight records indicate these may be interpreted as probably arising in a continuous orienting reaction to the unfamiliar space environment. The significance of these changes with respect to performance has not been demonstrated.

In the Gemini flights, there was a loss of bone density which reached its maximum on the 8th day of the flight. The skeletal calcium loss appeared to be progressive. A decrease in muscle mass followed a similar pattern. The reduction of red blood cell mass reached 20% after 8 days and apparently it leveled off at that stage. The loss of the cardiovascular fitness, as indicated by a tachycardia at rest and postural hypotension, was at maximum after 8 days and showed some improvement in the 14 day flight. Weight losses other than that attributed to muscle and calcium loss are primarily a fluid loss. These weight losses are very similar in both Russian and U.S. manned flights and appear to be independent of flight durations beyond 3 days. It may be said that Gemini 7 flight was primarily a medical experiments flight.

TABLE I—MEDICAL EXPERIMENTS/MEASUREMENTS CONDUCTED ON FLIGHT CREWS DURING PROJECT GEMINI

EXPERIMENT/MEASUREMENT INFLIGHT	Gemini-3 5 hours [1]	Gemini-4 98 hours [1]	Gemini-5 191 hours [1]	Gemini-6 26 hours [1]	Gemini-7 331 hours [1]	Gemini-8 11 hours [1]	Gemini-9 72 hours [1]	Gemini-10 71 hours [1]	Gemini-11 71 hours [1]	Gemini-12 95 hours [1]	Total
M001—Cardiovascular conditioning			X		X						2
M003—Inflight exerciser		X	X		X						3
M004—Inflight phonocardiogram		X	X		X						3
M006—Bioassays body fluids					X	X					2
M006—Bone demineralization		X	X		X						3
M007—Calcium balance study					X						1
M008—Inflight sleep analysis					X						1
M009—Human otolith function			X		X						1
Heart rate	X	X	X	X	X	X	X	X	X	X	10
Respiration rate	X	X	X	X	X	X	X	X	X	X	10
Blood pressure	X	X	X	X	X						5
Oral temperature	X	X	X	X	X	X	X	(3)	(3)	(3)	7
PREFLIGHT AND POSTFLIGHT: [2]											
Tilt table	X	X	X	X	X	(4)	X	X	X	X	10
Hematology [2]	X	X	X	X	X	X	X	X	X	X	10
A. Blood Volume		X	X		X			X	X	X	6
B. RBC Indices			X		X			X	X	X	5
C. Reticulocyte Court			X		X			X	X	X	5
Urine [2]	X	X	X	X	X	X	X	X			9
Exercise tolerance					X		X	X	X	X	5
Body weight	X	X	X	X	X		X	X		X	8

[1] To nearest hour.
[2] Standard blood and urine examinations, physical examinations, and verbal debriefings followed each flight.
[3] Available.
[4] Preflight only.

From: "A Review of Medical Results of Gemini 7 and Related Flights," NASA Space Medicine Directorate, Office of Manned Space Flight; held at Management Center, J. F. Kennedy Space Center, Florida, August 23, 1966.

See also tabulation presented in the testimony of Dr. Charles A. Berry of NASA at the hearing of November 17, 1969.

In the Apollo missions, the biomedical measurements made during flight are more properly characterized as monitoring than experimenting. The pre- and post-flight tests are experimental.

The experiments on the astronauts during Apollo flights included voice monitoring, electrocardiogram and respiration during the command module operations, and voice and electrocardiogram during the lunar module operations. In the Apollo missions there was a mean exposure ionizing radiation dose of 230 millirads.

The ground evaluations of the flight crew included physical examinations, hematological studies, immunological studies, biochemical studies, measurement of bone density, cardiovascular measurements with the application of lower body negative pressure, the exercise capacity and a routine microbiological study. The bioastronautic aspects of Apollo biomedical operations have been summarized by Dr. Humphreys and Dr. Berry in a report to the XXth International Astronautical Congress. They report that the astronauts have adapted well to the weightless environment, found it pleasant and have utilized the characteristics of the weightless environment in accomplishing their in-flight activity.

There are reported differences in work-sleep cycles. There are a number of possible causes of sleep disturbance, such as noise, the staggering of sleep periods, the unfamiliar environment and excitement. The Apollo crew made use of secobarbital for sleep and also D-amphetamine as a stimulant.

Some assessment of metabolic activity has been added in the Apollo flights from the calculations which can be made from the extravehicular mobility unit's performance. The estimates of activity on the lunar surface show values between 800 and 1100 BTU per hour. This is three to four times resting or moderate activity. All of the measurements and tests conducted in the Apollo flights have been carefully documented in the report of Doctors Humphreys and Berry.

I should like to refer now to those areas of investigation where a specific *experiment* should be conducted in Apollo applications in order to provide the information necessary for decisions concerning longer space flights. NASA now faces the opportunity to shift the emphasis in its missions from that of proving a technology to that of using a technology for scientific work. One of these areas would be the proper measurements for man to determine what his qualifications are for longer duration space flights. These studies should be undertaken not only to derive physiologic data in carefully designed experiments but also to show what man's proper role in the man-machine system in space operations may be.

In this author's opinion, a primary area for experimentation is determination of the actual compartments and mechanisms involved in the weight loss that occurs during flight. This will require the most carefully designed metabolic balance experiments done in such a manner so that the time course of the change is determined. The experiments must continue in the post-flight period for sufficient lengths of time to follow the recovery or return to the normal state. It is imperative that a careful pre-flight study be arranged. It is also important to determine the cariodvascular changes which take place which cause the increase in resting heart rate, the decreased exercise tolerance, and the decreased postural tolerance and the change in blood volume. The investigations should be directed toward elucidation of the mechanisms involved. The third major area for investigation will be the overall tests of behavior which will include performance, in the sense of performing tasks requiring dexterity, as well as logic and decision making; the behavioral patterns of sleep and wakefulness; and at least three indices of circadian rhythms. These three indices might be body temperature, analysis of the urine for potassium and for catecholamines and other organic substances.

The present Apollo follow on studies include an experiment on behavioral effects, an experiment on pulmonary function and energy metabolism, investigation in microbiology, investigations in nutrition and musculo-skeletal function, investigation of cardiovascular function, investigation in hematology and immunology, and some investigation in neurophysiology. These are being pursued in a somewhat haphazard fashion at the present time due to lack of definition of missions and goals. It is imperative that they be given a high priority such that the requirements of the experiment begin to dictate some of the engineering and operations decisions.

The medical aspects of an orbiting research laboratory were studied in great detail by the Space Medicine Advisory Group during the period January to August, 1964. These are published in NASA SP–86. Further experiments are outlined in the National Academy of Sciences Publications 1485 A and B, 1968 and

1967 respectively, concerned with *Physiology in the Space Environment*, "Circulation" and "Respiration."

In summary, I cannot emphasize too strongly that for space flight experiments to be significant, an extensive and well programmed ground based endeavor must be maintained to provide the testbed for the experiments and the reference data against which the experiments will be interpreted.

Mr. KARTH. Mr. Downing asked this question on a number of occasions, and you were one of the witnesses of whom he asked the question. I get a good deal of fan mail from all over the country—I shouldn't say fan mail—mail of various sorts. Here is one from a gentleman by the name of H. T. Rowe from Ridgewood, N.J., and he makes this statement in his second paragraph.

He says:

Despite disclaimers by some space scientists more intent on spectacular accomplishments than on the safety of their charges, even the layman can be reasonably certain that human systems, circulatory, digestive, respiratory, and so forth, that have evolved over eons under conditions of earth gravity probably will be adversely affected by long periods under zero g.

You agree with that?

Dr. CARLSON. Well, I think that discussions that we had in Space Science Board committees have listed in these two reports and in a third one which I don't have here, many of the possibilities that might be adversely affected. I think only tests will tell us whether it is so.

I mentioned in my text that one of the things which we could hypothetically or theoretically say would be altered was the cardiovascular system because our tests at 1 g indicate to us the distribution of fluids in the body and the actual amount of fluid in the body are conditioned by the 1 g field. We knew this would probably change.

So, I think that there are systems which will be affected. I would prefer not to say, at the moment, adversely.

Mr. KARTH. Do you think it really might be helpful, Doctor? Is that what you are saying?

Dr. CARLSON. No—well, to some extent.

Mr. KARTH. It has to affect it one way or the other; and if it isn't adversely, then to some degree it must be a helpful effect.

Dr. CARLSON. It would be adverse in the sense that some readjustment or some life support systems would be necessary to keep the man intact.

Mr. SYMINGTON. Will the Chairman yield?

Mr. KARTH. Yes.

Mr. SYMINGTON. Professor, we had testimony yesterday—I think it was by Dr. Berry who told us that weightlessness in fact might be good for you. And as we pursued the discussion it was also pointed out that the loss of calcium—I think we have mentioned that today—could be compensated for by exercise, that it could be stopped. I asked then, and I would like to ask you now, is the loss of calcium an indicia of the helpfulness of weightlessness or is it an indicia of the problems that it can give us?

Dr. CARLSON. I would class it as one of the problems, for two reasons. I think in the first place if the calcium is liberated from bone rapidly enough, then the clearance of calcium is a problem; and, secondly, since the man is coming back to the 1 g. environment, he will essentially be in a state in which he might actually well be fit for the space environment rather than the 1 g. environment.

Mr. SYMINGTON. So when we ask this question of whether or not it is good for man to be in a state of weightlessness, I think that we mean to ask, is it good for man after he gets back? Is it good for an earthman? Not just simply can he adapt to that system and then leave ours and continue indefinitely there or at least until some aging process does overtake him? It is in that context, I think, that we ask the question. And I take it that you are answering that weightlessness in fact might make a better man or could?

Dr. CARLSON. I am not sure I understood the question. Let me rephrase it and see if I have it.

Mr. SYMINGTON. When the chairman asked if weightlessness is adverse and you said you weren't sure——

Dr. CARLSON. And I qualified it.

Mr. SYMINGTON (continuing). He said it could even be helpful and you said, yes, in some instances. I guess what this committee would like is your judgment as to whether the net effect of weightlessness could be considered beneficial to man even after he returns to earth.

Dr. CARLSON. In the context of your question as specifically put with respect to his return to earth, then many of the experiments and measurements that are suggested in these documents and many NASA documents are designed to determine the extent to which change takes place in weightlessness and once that has been determined, then the judgment could be made as to whether it would be a detriment when he returned, and this would then be the basis for whatever supportive measures might be used in the spacecraft in order to maintain these systems.

Mr. SYMINGTON. Is the exercise that is prescribed for him, if he were to exercise in a weightless state, would it be your judgment he really wouldn't need to do that exercise, that eventually his system would accommodate to weightlessness and he could live that way as long as he wasn't in a gravitational situation?

Dr. CARLSON. Yes; in a sense. After all, we are fit for what we do. Actually it has been shown on the astronauts the circulation and the muscle mass are different from what they are on me even though I try to keep fit. The muscle mass of the weight lifters is quite different than the muscle mass of those who don't life weights. So the adjustment is adaptive to the requirement on the system.

Mr. SYMINGTON. So a perfect man as we conceive of him on earth might be an imperfect specimen in space?

Dr. CARLSON. He would be different.

Mr. SYMINGTON. Yet we are not contemplating adapting man to the space environment permanently?

Dr. CARLSON. I think the extent of many of these experiments, I said, was to determine the extent to which a change takes place and try to compensate for it with the proper supportive measures.

Mr. SYMINGTON. If compensation in the form of deliberate exercise is required, say, in space over a period of time, that places a certain strain on the will power, and I think the psychological state of mind of an astronaut, don't you? It is an extra. They are always complaining a little about how much they have to do. Certainly to hook yourself into some piece of equipment and tug on it is something to do which, if removed from their daily chores, would be a release, I would think, of some kind.

Dr. CARLSON. It would certainly be part of the regime.

Mr. SYMINGTON. Would you have any judgment at this time as to whether the regime required to preserve an earth-oriented man in a state of weightlessness would be sufficiently difficult for him to justify attempting to create an artificial gravity system for prolonged periods in space?

Dr. CARLSON. Again I believe the experiments that are presently proposed and many of which we hope will be accomplished in Apollo Applications will bring us some answers to this question and that is why I have qualified my remark about the definition of the technology for going to Mars until we have had sufficient testing to find out.

Mr. SYMINGTON. In other words, a 400-day mission in space might not be a healthy experience in a state of weightlessness for man—let me scratch that and ask more directly. It is conceivable that an artificial gravity would be a requirement if such a trip as one to Mars were made?

Dr. CARLSON. Yes; it is conceivable. It might turn out to be desirable.

Mr. SYMINGTON. The spacecraft itself is going to be designed with such a system, or it isn't. You would not wish to see a great investment put into the spacecraft on the assumption an artificial gravity system is not required before we are sure it is not required.

Dr. CARLSON. That is correct.

Mr. SYMINGTON. That is all I have.

Mr. KARTH. Professor, are you at all familiar with this report of the Space Science and Technology Panel?

Dr. CARLSON. No, sir; I just have seen it.

Mr. KARTH. Let me read to you a few paragraphs and ask you for comment thereon.

One part of this report says, and I quote:

> Why is it important to understand man's role in space and why should NASA modify its approach to biomedicine in a major way? We will explore these questions in detail in our report.
>
> Quite briefly, we believe the persuasive element is cost, not only in terms of expenditures to achieve operational objectives but also cost in terms of potential social benefits that are needlessly lost if manned flight programs continue to be pursued as in the past.

Do you agree with that?

Dr. CARLSON. I agree that it is a question worth exploring, the question in the report. I think I would reply that a good many of these technologies are useful in the sense of having earthbound applications, if you will, and serve certainly as potential employment for large numbers of people.

Mr. KARTH. What they are saying really is we have been so hasty in moving forward in the field of technological development that we have failed to consider these other important questions like, for example, the "potential social benefits that are needlessly lost if manned flight programs continue to be pursued as they were in the past."

You would agree with that?

Dr. CARLSON. I would be willing to debate as to whether man's social needs are lost as a result of pursuing the space program in the way in which the Space Task Group recommended to the President.

Mr. KARTH. I don't understand you.

Dr. CARLSON. I believe we can do both.

Mr. KARTH. The fact of the matter is we have not. And I think this recommendation is based on what we have done rather than what we could do, or what we should have done, or what we ought to do in the future. They say that "we believe the persuasive element is cost, not only in terms of expenditures to achieve operational objectives." Our objective was, as you say, to get to the moon, and I think most everybody agrees under the circumstances of the national commitment we really didn't have much of a choice in the matter. We committed ourselves and we did it. The Congress approved; the American people accepted it really through their elected representatives. So they say, "we believe the persuasive element is cost, not only in terms of expenditures to achieve operational objectives but also cost in terms of potential social benefits that are needlessly lost if manned flight programs continue to be pursued as in the past."

What they are saying is we ought not do again what we did during the last 10 years in terms of picking a national operational objective and then pursuing it in an operational manner and, as a result of that, close our eyes to the biomedical benefits that might be derived therefrom if we pursued it in a different fashion. I take it that you agree?

Dr. CARLSON. I can only agree we shouldn't close our eyes to the other.

Mr. KARTH. They continue on to say:

We believe that man will continue to venture into space because of his innate desire to explore the limits of his environment. NASA will respond by defining a continuing series of manned programs, programs that promise to be successful, in the sense that Mercury and Gemini were successful. But these programs—whatever their total cost—will be wasteful if they do not utilize man effectively. They will be most wasteful if they fail to test the relative virtues of manned and unmanned alternatives for all classes of major space objectives.

You agree with that?

Dr. CARLSON. Completely.

Mr. KARTH. Again I quote, and these are complete paragraphs I am quoting, Professor, in an effort to not take things out of context which might be misleading.

In order to define an appropriate mix of manned and unmanned operations, NASA will need to "qualify man for space flight" in the broadest sense. That is, NASA should pursue a biomedical program which explores the optimization of man's role in space, the limitations on his effectiveness and means to circumvent those limitations; in short, a program to determine the best use of man as a space subsystem in interaction with automated subsystems.

You agree with that?

Dr. CARLSON. Yes. That really reiterates what they said in 1967 in their report.

Mr. KARTH. Yes, sir. They do point out in this report, however, and I think rightly so, the reason why the powers that be—the President, the space agency, the Bureau of the Budget, and so forth—the reasons why their 1967 recommendations and prior to that even, their 1962 and 1963 recommendations, were not followed or adhered to in any effective sense, or why they were overlooked—and that is because we had already decided on the national objective of landing a man on the moon in this decade. So, with this overriding national objective, we could not do both, Professor, is what they say. But they say now the situation is different. We have accomplished this national objective

and now we have to look to the future. What is best for the total country is best for the total space program is what they are saying.

I think that you and I can agree that is probably a good philosophical position to take.

Dr. CARLSON. Yes, indeed.

Mr. KARTH. There are a couple of other things that I just wanted to explore briefly with you in terms of that report. On page 19 in their recommendations, they say and I quote:

Now, the maintenance of a viable NASA manned-flight program may very well depend on a strong and basically redirected biomedical effort. In any case we believe that great benefit to man on earth would derive from the development of the research capabilities required for space biomedicine.

You agree with that?

Dr. CARLSON. Yes; I think that is what I tried to say in my presentation.

Mr. KARTH. Again they say and I quote:

Under the present budgetary constraints, post-Apollo manned space flight programs are being reduced in scope and slipped in time and manned planetary exploration is no longer an immediate concern.

I am not sure they talked to everybody in Government to come to that conclusion, but they go on to say:

NASA now has the time to design and implement programs for studies of manned flight, for the development of ground-based programs and institutions in the scientific community which support these studies, and for the strengthening of its overall biomedical capabilities.

You agree with that?

Dr. CARLSON. Yes, sir.

Mr. KARTH. One of their recommendations under the heading "Applied Goals," is the one that is itemized as recommendation (f) and this is what it says; this is what their recommendation is: "Development of techniques for circumventing limitations, through development of 'telefactors' for man-controlled remote operations."

Are you familiar with the word "telefactor"?

Dr. CARLSON. Actually that was introduced into this discussion, I think, in the Space Science Board meeting in Iowa which is now 10 years or more ago. That is the same recommendation that appears there and I agree that it should be explored.

Mr. KARTH. Would you explain for the benefit of the chairman of this committee, at least, what you mean by the word "telefactor"?

Dr. CARLSON. I understand it is any extension of man's capability to operate, and a very good example is the Atomic Energy Commission where men sit and manipulate devices which do things for them in areas in which they cannot be. So that in a sense you extend man's environment by these particular devices which are electronically controlled and which he watches in a scope or something.

Mr. KARTH. And you do this from the ground?

Dr. CARLSON. That would be the ultimate possibility, I guess.

Mr. KARTH. In their recommendations, captioned by the words, "Research Facilities," they make this recommendation and I quote:

While a broad range of composite biomedical research facilities and capabilities has evolved within the various elements of the DOD, AEC and NIH, the degree to which these Federal resources have been utilized in detailed support of the space program has been limited, as has development or support of

biomedical capabilities within universities. It is toward evolution and use of such assets that the long-term biomedical program plan must be directed, since it is clearly impractical to consider establishment within NASA of the many and varied biomedical laboratories, or the extensive and versatile investigative staffs required.

You agree with that?

Dr. CARLSON. Yes; if you will accept the fact that within NASA as within NIH and the Department of Defense there are certain facilities which are really critical for their operations; so they need to have a certain in-house capability. I think that is probably implied in this recommendation.

Mr. KARTH. Your point is that NASA would have to have certain critical in-house capabilities. Yes, I think that is true, particularly if AEC, DOD, NIH, or the universities do not have whatever sophisticated facilities might be required to do the job. Then it may well be that NASA ought to have those as in-house facilities rather than construct them at some university that would have a particular advantage over all others thereafter.

Dr. CARLSON. And as such they become a national facility.

Mr. KARTH. Yes, indeed.

I have no further questions, Professor.

Mr. Dickinson.

Mr. DICKINSON. No.

Mr. KARTH. Thank you very much, Professor.

I am sorry we have continued so long today. I want to now recognize Dr. Farner who, I understand, had some airplane problems and has just now arrived. He was to land at National Airport, but due to fog and other elemental causes was forced to land at Dulles and take a hurried cab ride in here.

Professor Farner, we are very happy to have you with us.

Professor Farner is chairman of the Department of Zoology, University of Washington, Seattle, and also chairman of the Division of Biology of the National Academy of Sciences.

Professor, we are indeed pleased that you can be here and give us the benefit of your testimony so that the committee and Congress can make judgments on the future course of our biological and biomedical efforts in space.

Would you proceed, sir?

STATEMENT OF PROF. DONALD FARNER, CHAIRMAN OF THE DEPARTMENT OF ZOOLOGY OF THE UNIVERSITY OF WASHINGTON, SEATTLE, AND CHAIRMAN OF THE DIVISION OF BIOLOGY, NATIONAL ACADEMY OF SCIENCES

Dr. FARNER. I should say, first, that I do not have a prepared statement because my contact with this hearing consists of a telephone call that I received last week in Copenhagen and one I received in Seattle yesterday morning from Mr. Dickinson.

I am assuming that I have been asked to come here because of the association that I had with the space biology summer study at Santa Cruz last July. Before I proceed, I should point out that this participation in the summer study is really my first experience with the space biology program; so I do not talk from the wealth of experience that Professor Carlson has.

The space biology summer study was conducted by a group of individuals, many of them members of the National Academy, drawn very broadly from the biological community in the United States. Some of the participants were, I think, basically not sympathetic with the space biology program. Many of them were sympathetic. Many were involved with the space biology program. Others like me had had no previous experience.

So if I may, sir, I think that I will give you relatively briefly my own analysis of the position of this group.

Mr. KARTH. Please do.

Dr. FARNER. These do not represent my own personal opinions about various aspects of the program, but my own analysis of this group which I think is representative of American biology.

I would say, first, that there is a general feeling that the space biology program is an important component of the entire space program. I think that biologists or at least those that were there tend to look at the space biology program in perhaps five or six components, and I would like to very briefly speak about these.

The first two components I would label tentatively as primarily basic science elements. I am certain you are familiar with them already. They are, first of all, the role of gravity with respect to living systems. I think that it was just about a century ago that Charles Darwin pointed out that gravity is one of the most pervasive environmental factors and yet we had no way at that time to study its role. But now with the development of modern space technology, potentially we have this possibility.

Mr. KARTH. But it was the summer study group's judgment that we hadn't really done a job in this area?

Dr. FARNER. I would summarize it by saying that we are just barely into it.

Mr. KARTH. May I ask you one other question at this point, Professor. Before you came in I had read a paragraph from a letter I received from a gentleman in New Jersey. Let me just read it to you and ask for comment. He says:

> Despite disclaimers by some space scientists more intent on spectacular accomplishments than on the safety of their charges, even the layman can be reasonably certain that human systems, circulatory, digestive, respiratory, etc., that have evolved over eons under conditions of earth gravity probably will be adversely affected by long periods under zero g.

You agree with that?

Dr. FARNER. This is difficult to answer. But I am apprehensive that such would be the case.

Mr. KARTH. Thank you.

Dr. FARNER. The second basic science component as I am labeling them is that of time structure of living systems. Organisms on this earth have evolved in a 24-hour system, a 365-day system, and so forth. In all cases in these periodic functions we still are not completely certain as to the nature of the internal mechanisms that are basic to daily cycles, annual cycles, monthly cycles, and so forth.

As you may know, there is a substantial controversy in biology, especially with respect to daily cycles, as to whether these cycles are truly endogenous and simply phased by the ordinary 24-hour cycle of day and night or whether they are actually driven by the environmental changes that occur every 24 hours.

I think that the whole field of 24-hour periodicities has so many ramifications insofar in human biology, and the biology of domestic species, that a resolution of the problem of the true nature of these 24-hour oscillating systems is very important.

There was a strong, but not unanimous feeling at the summer study that the ultimate resolution of the nature of these periodicities probably can only come with eccentric orbital experiments or with deep space experiments.

I should point out, of course, that an understanding of circadian or daily periodicities has a strong bearing insofar as the performance of astronauts is concerned.

To hurry on, the second group of components I would label as basic scientific investigations that have a relatively immediate application insofar as manned space vehicles are concerned.

I think that I need mention this only briefly because I am certain Professor Carlson has already had things to say about this. First of all the emphasis was placed on the desirability of getting more precise measurements on the astronauts themselves; and, second——

Mr. KARTH. Could you enumerate those desirable experiments for the record, Professor, not at this point if you choose not to, but will you supply it for the record?

Dr. FARNER. I will be very glad to.

(The experiments referred to are enumerated in a letter from Dr. Farner included at the end of this days' testimony.)

Dr. FARNER. In the second place, despite the incident that immediately preceded the summer study, there was a strong feeling on the part of some of the participants we must press forward with the sophisticated but still classical mammalian physiological approach using subhuman primates and other mammals.

Then, finally, the third group of categories might be best designated as scientific spin-offs. I think that they are extremely important and were regarded by some participants as most important.

I have in mind here first the tremendous potentiality of remote environmental sensing at this time in which we are beginning to recognize that an understanding of environmental changes requires constant monitoring of selected parameters of the environment.

Then, finally, in this same group of categories, it was recognized that the use of satellites could permit a tremendous breakthrough in the understanding of animal movements and migration. Within these categories of animal movements, of course, are the movements of many economically important species, including fish, large game animals, and even domestic animals.

I think, although this is a very condensed statement, it summarizes the thinking, as I judge it, from my colleagues at the summer study.

Mr. KARTH. I think one of your points there, Professor, was the continued use of primates or subhuman animals. Did they take any position at all on what kind of experimentation ought to be carried out on man, or whether or not man himself ought to be used as a guinea pig, in part or to what degree?

Dr. FARNER. I did not hear the discussions in this particular group; so I am unable to inform you.

Mr. KARTH. That was not one of their recommendations at any rate?

Dr. FARNER. No; except to return to the point of getting more physiological data from astronauts actually in flight.

Mr. KARTH. I see. That does, I think, cover that point.

Dr. FARNER. I will add an additional point. I sense a feeling of apprehension concerning step by step deeper thrusts of man into space for longer periods of time without the necessary preliminary experiments on mammals including subhuman primates.

Mr. KARTH. We have been exploring that, Professor, particularly in the sense of whether or not one could extrapolate with any degree of validity—*any* degree of validity—the results of experiments on those kinds of animals to what the results or the effects of similar situations might be on man himself.

There has been a good deal of testimony on this point. Would you care to benefit the committee and the record with your feelings on this matter of extrapolating the results of experiments carried out on subhuman primates to man himself?

Dr. FARNER. Sir, you are pressing me a little bit beyond my field of immediate knowledge, but I think I would generalize to say that such an approach, throughout the history of physiology, has been sufficiently successful so that I would not feel that we should in any way abandon it as an approach in space physiology.

Mr. KARTH. So you feel that an extrapolation can be made?

Dr. FARNER. With caution.

Mr. KARTH. With caution.

Professor, are you at all familiar with the report of the Space Science and Technology Panel of the President's Scientific Advisory Committee—the report they recently made?

Dr. FARNER. No; I believe that I am not.

Mr. KARTH. In the evolution of man's role in space, this is what they say, and I quote one paragraph: "We cannot answer this question with assurance for the long term"—that is, they end up the previous paragraph by saying, "Then why manned flight?" They go on to say:

> We cannot answer this question with assurance for the long term. We expect that man will play an important role, but we have an imperfect vision of what that role will be. The degree to which we can identify man's role depends critically upon information that does not yet exist. The necessary experiments have yet to be performed, either on the ground or in space, that will qualify man in the broad sense, for future space flight.

Do you agree with that statement?

Dr. FARNER. Yes; I think that I do.

Mr. KARTH. I wonder, Professor, if for the record you could also give us—not at this time, but in the near future—specific recommendations either based upon the Santa Cruz summer study or as an expert opinion of your own on what specific course we ought to follow in future manned space flight programs as it relates to the whole question of bioscience or medical science.

Dr. FARNER. Yes, sir; I shall be pleased to do so.

Mr. KARTH. Thank you very much, Professor Farner.

Pursuant to the invitation of the chairman, further comments were submitted by Dr. Farner, as follows:

UNIVERSITY OF WASHINGTON,
DEPARTMENT OF ZOOLOGY,
Seattle, Wash., November 26, 1969.

Hon. JOSEPH E. KARTH,
U.S. House of Representatives,
Washington, D.C.

MY DEAR SIR: During the course of my testimony before the Subcommittee on November 18 you requested that I transmit for the record my own recommendations concerning biomedical investigations in the space program.

The opinions and recommendations transmitted herein, although perhaps similar and sometimes even identical with views expressed by others, are nevertheless my own as an interested biologist and, in no way are intended to represent the position of any group or organization. Other than having served as a participant in the Summer Study on the Space Biology Program, sponsored by the National Academy of Sciences at Crown College, University of California, Santa Cruz, in July 1969, I have not been involved in the space biology program. This has both disadvantages and advantages with the latter, for the purposes of this communication, possibly outweighing the disadvantages.

Without examining the rationale therein, I accept our national commitment to a program of the exploration and investigation of space, by manned and unmanned vehicles, and anticipate its continuation for the foreseeable future. This offers a multitude of unique opportunities for enhancement of our knowledge in essentially all disciplines of natural science. Having accepted the commitment to the space program, I am compelled, nevertheless, to observe in passing that the cost of a single Apollo spacecraft launched by a Saturn 5 rocket is of approximately the same order of magnitude as the entire annual budget of the National Science Foundation. I do this as a reminder of the very great responsibility that one assumes in making recommendations concerning the space program. My own assessment of costs, benefits and competition for funds leads me to the conclusion that exploration of the planets by manned space vehicles is probably at least two decades removed. Furthermore, it seems that a similar period will be required to develop adequate life-sustaining systems and a satisfactory assessment of the capability of man as an element in the technologically complex system that will be employed in planetary exploration.

It seems patently clear that prominent among the motivations in our space programs are those human qualities that have always caused explorers to venture into the unknown, that cause mountaineers to scale the highest and most rugged peaks, and that cause athletes to strive to win in competitive sports. Fortunately these human qualities are irrepressible; without them there could be no successful space program. The critical philosophical problem however, is to couple these motivations with a program of scientific investigations that will at least partially justify the very substantial costs of space exploration to our national economy and society.

My recommendations are made in light of observations and assumptions set down in the two paragraphs immediately above. My recommendations for the biomedical component of the space program involve three closely interrelated elements. The close relationship of these elements is an inevitable consequence of the unity of biology. The order presentation of the elements is not necessarily an order of priority.

1. *Man in Space.*—This element is concerned with the accumulation of an adequate body of knowledge concerning the performance of man in space over substantial periods of time. The objectives transcend those of the minimal knowledge necessary for maintenance, safety, and survival to the attainment of a fund of physiological and psychological knowledge that will permit a sound comprehension of the potential role of man as a component of the complex technological systems of planetary exploration for protracted periods of time. Whereas major concern must be directed to the prolonged effects of weightlessness, the effects of crowding in confined space, and the behavior of periodic functions over prolonged periods under space conditions must also receive extensive attention. It is my impression that our present knowledge and capability for extrapolation are quite inadequate. In my opinion, a satisfactory body of knowledge cannot be obtained by an incremental approach with human subjects in space. Rather, it can be attained only with carefully planned experiments with other mammals, including infrahuman primates in biosatellites.

Proper extrapolation from animal experiments can be effected only with the accumulation of more extensive and precise data on astronauts so that accurate transformation or scaling factors can be established. Data needed, and practically procurable, from man in space include estimation of endocrine performance (from blood and urine samples, frozen and properly labelled), oxygen uptake and carbon dioxide release, motor performance, circadian and other periodicities, water intake and loss (all routes), electrolyte balance, electrocardiograms, electroencephalograms, blood pressure, heart rate, etc. The procurement of such data may well require manned flights designed primarily for such purposes. The importance of adequate and appropriate earth-based experiments cannot be overemphasized. A manned spaced laboratory may be essential. Further monitoring, improved measurement, and investigation of radiation in the space environment, with special attention to high-velocity, heavy atomic nuclei, is necessary.

2. *Basic biology.*—This element is concerned with the use of unique aspects of the space environment for the investigation of properties of living systems that cannot be investigated on earth. Gravity is a common environmental component for all organisms. Yet our knowledge of the role of gravity in the processes of early embryonic and later development and in the normal functions of adult animals is ridiculously fragmentary. Although some information on plants can be obtained by periodic reversal of gravity, such procedures offer little or no promise for investigations on animals. "Downward" extrapolation of curves based on experiments employing gravitational values of 1G and greater are of dubious value. Sorely needed are data on many, many functions and processes at gravities between zero and 1G. These can be obtained only in experimnts in space. Although there are serious technical problems, I am convinced that some useful experiments can be obtained from experiments in biosatellites provided that they are accompanied by appropriate, preliminary and simultaneous earth-based investigations. However, the most significant investigations on the role of gravity in developmental processes and normal functions in adults will probably await the development of manned orbiting laboratories since much of the experimental work must be carried on by successive approximations requiring more or less constant attention by the investigator. In my opinion, experiments in space on the role of gravity in the processes of development, differentiation, and maturation will make very fundamental contributions to our understanding of these important functions.

Other important aspects of the earth environment are the characteristic physical periodicities in which organisms have evolved and to which they have become adapted. I shall comment here only on daily periodicities. In their evolution, organisms have evolved daily periodicities (circadian, or approximately daily when held in "constant" conditions) that permit them to "predict" the arrival of dawn and dusk. These periodic functions also serve in other ways as biological chronometers. Their very great importance in the normal function of plants and animals, including man, is only now being fully recognized.

There persists today a major controversy as to whether these periodicities are derived from endogenous oscillators that are entrained normally by the natural 24-hour light-dark cycle *or* whether the observed periodicities are directly driven by external physical periodicities (*i.e.* no endogenous oscillators). Although it is theoretically possible to construct on earth chambers that are completely free of all 24-hour physical periodicities, I strongly suspect that the resolution of the controversy can only be attained by placing organisms in a space environment beyond the influence of terrestrial, 24-hour periodicities. However beyond the resolution of the basis of daily or circadian periodicities, and regardless of the etiologic basis, much of importance can be learned from their performance in a weightless, aperiodic or non-24-hour periodic environment.

I view these potential contributions to basic biological science as part of an almost continuous spectrum of potential contributions of the space program to the natural sciences. However, an important, obvious difference between the biological and physical sciences must be emphasized here. In general, space research in the physical sciences involves measurements and observations of phenomena that exist, at least in the state or condition under study, only in space. Space biology, on the other hand, involves the use of certain unique parameters of space as an environment into which earth phenomena (living organisms) are inserted for experimental purposes. I present this simple reminder of this basic difference only to enter the plea that although very different philosophical approaches are involved, both are important in the contribution of the space program to natural science. It seems clear that the importance of both has

not always had general acceptance in the planning and decision-making processes in NASA.

3. *Remote sensing and tracking.*—In the strict sense this is not space biology and has no relationship to manned space flight programs. Rather it is a cluster of important spinoffs from the space program. In these days of rightful concern about the deteriorating global environment, and further, in view of potentially great scientific and economic benefits, there is an obligation through NASA to science and to the public to exploit these spinoffs effectively. The potential role of remote sensing in information-gathering on biological resources (distribution of vegetation, phenology, distribution of soil types, plant disease, insect infestations, etc.) is enormous. Our knowledge of the details of migration and other movements of animal, many of which are of economic importance, is surprisingly meager. The use of satellites, especially with the further miniaturization of transmitting units, can add enormously to our present scanty fund of knowledge.

This, Sir, in somewhat general language, constitute my recommendations concerning the biomedical research in the space program for the decade immediately ahead.

I should like to add a few additional comments.

Although I view the operation of NASA very much from the outside, I nevertheless sense a lack of consistent coordination and long-range planning with respect to its role in biomedical science. Unquestionably this can be attributed in some part to the overall problem of fiscal support. But I am inclined to attribute a more substantial fraction of this difficulty to an underemphasis of the role of NASA as a contributor to natural science, in general, and to biomedical science specifically. To me it seems essential that a knowledgeable biomedical scientist be involved constantly in the higher echelon of the decision-making apparatus. The success of the biomedical component of the space program, including the manned spaceflight components, will require the interest and participation of a much broader segment of the biomedical community. This can come only with a more consistent and stable biomedical program and an allocation of a more substantial fraction of the resources of NASA to research and development in biomedical research. It is my estimate, although somewhat crude, that the program outlined above would require an approximately ten-fold increase in fiscal support. Although I am largely unfamiliar with the internal administration of NASA, I nevertheless take the liberty of emphasizing the importance of a functional dichotomy between the operational medical functions and biomedical research and development.

If there is any way in which I can be of further assistance I shall be most pleased to respond.

Sincerely yours,

DONALD S. FARNER,
Professor of Zoophysiology and
Chairman, Department of Zoology.

Mr. KARTH. I want to announce that today's session is the last of this series. The hearing that was originally scheduled for next Monday has been canceled due to the inability of the witness to make it, and I am not so sure now that it is important to reschedule that. At any rate, we have no plans at the moment to do so.

So this session ends the series of inquiries we are making into the future of the bioscience program, as directed by Chairman Miller of California.

Again, I want to thank all of you very much for honoring us with your presence and for the helpful testimony you have given. I would only suggest that in addition to those things we have asked you to supply for the record, if you feel there is something you did not provide the committee with that might benefit the committee in making judgments on this question, why, please feel free to do so; and if there is any information that this committee might provide you with, please feel free to make that request of the committee.

If there are no further questions, the meeting is adjourned.

(Whereupon, at 12:34 p.m., the subcommittee adjourned to the call of the Chair.)